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Overview of Energy Audits

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"OVERVIEW OF ENERGY AUDITS" MANUAL

The Prelude

Energy audit is a tool to identify areas where energy can be conserved. Normally a facility/unit engages consultant(s) to carry out energy audit and may or may not implement all the recommendations. However, no system is put in place to monitor energy consumption at various equipment/department, etc., and do energy accounting at a regular interval. The financial system has provisions for internal audit and external audit both. No money is spent without internal audit. However, it is not possible to spend the energy only after internal energy audit. This process can be served to a large extent by having regular energy accounting system in place. The data collected during energy accounting must be internally analyzed at a regular interval. This would help in keeping tab on energy expenditure and any increase once noticed must be analyzed for the reason thereof leading to corrective action. The best example is monitoring fuel consumption in the car. Only when after monitoring of fuel consumption will it be clear if it has increased and corrective action is required. Thus, there is a need to have an energy accounting system in place to derive maximum and regular benefit of an energy audit.

Therefore, the energy audit consultant must ensure to place a system of regular energy monitoring and accounting. This will help in sustaining the energy efficiency of various system/subsystem/equipment (as the case may be).

ENERGY ACCOUNTING

Seven Reasons For Energy Accounting

Before you can manage energy costs, you have to know what they are! Energy accounting provides feedback on how much energy your organization uses, and how much it costs. It also provides a means to effectively communicate energy data that facility staff, building occupants and managers can use to improve cost management. Energy accounting will help your organization:

- **Record and attribute energy consumption and costs:**

  Energy costs depend on the amount consumed and it's price. In an organization with many facilities, energy accounting makes it possible to compare energy use and cost among facilities and to monitor how energy use changes over time. By communicating this information, those responsible for managing energy costs — maintenance staff, site managers, or others — can get feedback on how they are doing.

- **Troubleshoot energy problems and billing errors:**

  By consistently tracking energy use, you can identify problems. A sudden unexplained increase in consumption, for instance, means it's time to investigate the site for the cause. Billing errors can be caught, too.

- **Provide a basis for prioritizing energy capital investments:**

  Find out which facilities have the highest energy costs, and consider targeting them for energy retrofits or other energy management efforts.

- **Evaluate energy program success and communicate results:**

  Did you save what you thought you would from your energy management efforts? How did the actual dollar savings from your lighting or HVAC retrofit compare to the savings predicted by your vendor or contractor? Without energy accounting, it's virtually impossible to answer these questions.

  Once you determine the results of energy management activities, it's important to communicate this information to decision makers and implementers who were responsible for the activities. Energy accounting reports and graphs are the tools for this important feedback.

- **Create incentives for energy management:**

  It's often difficult to get anyone in an organization to take the time and responsibility required for carrying out energy management activities because there is little incentive to take on the task. A maintenance director or site manager may not see much benefit in reducing energy costs if all of the savings revert to the general fund, or if lower energy bills only result in smaller allocations for utility costs in next year's budget.

  To remedy this "disconnect" between responsibility and benefits, many organizations have created incentives for energy cost management by sharing energy savings. Energy accounting makes it possible to set quantifiable energy cost reduction goals. One city plans to reward the facilities team by using realized energy savings to augment the facility management budget for the next year. This way, those responsible for cost-cutting measures reap the benefits.

  Many school districts have shared savings with individual schools that cut costs through student energy patrols or other "behavioral" energy management activities.

- **Budget more accurately:**

  Energy accounting gives a historical look at costs that will help you budget more realistically for the future.

- **Position your organization to shop for lower prices for energy in a changing electricity market:**
  The market for electricity is changing rapidly due to regulatory reforms and increased competition between electricity suppliers. These changes parallel similar changes that occurred as the natural gas industry was deregulated, which resulted in significantly lower prices for knowledgeable consumers.

In order for your organization to take advantage of the potential for lower electricity prices, you will need to understand how electricity is priced (see the section, “Understanding Utility Bills”), and you will need to know your “electric load profile.” This means knowing how much electricity your organization consumes during different times of the day and different seasons of the year.

By setting up an energy accounting system and understanding the details of how energy is priced, you will be better prepared to negotiate for the best electricity deals in a changing market. If you are a large user, you may be able to negotiate directly with electricity producers in the future. If you are a small user, you may want to pool with other consumers. An “aggregator” may be able to help small users get a better deal by pooling electricity purchases.

The more knowledge you have of your precise electricity needs, the better chance you will have of paying lower prices. Energy accounting methods and software are likely to change significantly to accommodate the changing electricity market. Now is the time to get in on the ground floor and develop expertise in understanding your energy usage.

Getting Started for Energy Accounting

Before you start tracking energy, you need to get organized. Once you make sure that key people in your organization understand the benefits and costs of energy accounting, you should learn what data you will need to collect, and develop a plan for communicating energy data so it can be used.

- **Identify your goals and objectives, and consider how energy accounting information will be used:**

  You must be able to clearly explain why you need energy accounting before you can “sell” the idea to your organization. Having clear goals and objectives will help you decide what tools you will need. This box lists sample goals and objectives.

  It is important to be clear about how energy accounting information is to be used. Will it be used primarily by the facilities or maintenance department to troubleshoot equipment problems? Will it help track performance of new energy efficient equipment installations? Will it provide feedback to site managers or administrators who are responsible for containing energy costs? Will it be used to annually budget for utility costs?

  Daily or monthly energy use and cost reports must be sent to the chief executive of the organization, which would definitely keep the managers on toes to keep energy costs from escalating.

A typical example of goals and objectives of energy accounting

GOALS

- Manage energy costs
- Promote energy/environmental awareness
- Manage water and other resource costs

OBJECTIVES

- Verify savings from energy retrofits
- Motivate staff to manage energy costs
- Set energy cost savings goals and monetary incentives
- Prioritize sites for energy retrofits
- Troubleshoot unusual consumption increases
- Find billing errors
- Prepare to negotiate for price and service as electricity undergoes deregulation

- **Get commitment from decision makers or management:**

  Once you know how energy accounting can serve organizational goals, you need to get sufficient organizational "buy-in" to make your program a success.

  Energy accounting is often part of a larger energy management effort. If so, a city council or school board resolution in support of the program goals can help create visibility and encourage participation. In large organizations, the decision to allocate resources to energy accounting may be made by senior facility management staff. Since energy accounting and energy management is likely to involve staff across departments, it's best to get "buy-in" at the highest and broadest level possible.

  As you involve decision makers in the process, make sure to discuss both your organization's needs and the constraints of energy accounting. Consider the cost of purchasing software, and, especially, the amount of staff time needed to set up and maintain an energy accounting system.

  It may take more than 40 hours over several months to make the contacts and obtain and input the data needed to set up a computerized energy accounting system. Once the system is set up, acquiring and entering monthly data will take competent clerical staff one to eight hours per month or more, depending on the number of meters tracked. (Electronic data transfer can reduce the time but may increase the cost.) Additional professional staff time will be needed periodically to prepare reports and communicate energy accounting results. If you plan to have a consultant assist with energy accounting, be sure the consultant costs and responsibilities are clear.

- **Consider a system of communication:**

  What kinds of reports and graphs will be needed, and by whom? When and how will information be reported? Make sure you get the right information to the right people, at the right time. With rapid feedback, maintenance staff can respond to changes in energy consumption by looking for a problem at the facility. Monthly or quarterly reports to site administrators comparing present to baseline usage, or analyzing trends in consumption, can help to periodically direct attention to energy management.

- **Consider what tools (including software) you will need for an energy accounting system:**

  Based on your organization's needs and constraints, what kind of energy tracking software (if any) will you purchase? See the sections on Means of Energy Accounting (pages 15-18) and Tips for Selecting Software (pages 23-24).

- **Obtain necessary data:**

  The information you collect will depend on the level of detail you wish to track and on the type of system and/or software you will use.

  Generally, this will include an inventory of buildings detailing square footage, utility accounts and meters for each building or facility, and billing histories going back at least 12 months — preferably 36 months — for each meter. Weather data and information on such variables as occupancy rates and schedules may also be required.

  Do not underestimate the time involved in this step! It may take several months to get billing data from your utility. In some cases, it may be difficult to correlate accounts with buildings, particularly if records of meter locations are not available.

Implication

Energy accounting can help your organization understand how energy is used and can help motivate people to take actions that can result in significant utility cost savings. However, many organizations do not realize the full benefit of tracking energy consumption and cost.

The biggest pitfalls that keep organizations from effectively using energy accounting data are:

- Lack of staff time and commitment in maintaining the system.
- Failure to communicate the results to the right people.

To make the most of energy accounting, it is crucial to allocate sufficient staff time for setting up and maintaining the system, and to develop a system of communication with administrators, facilities staff, and others whose decisions affect energy use.

Energy accounting by itself will not save energy. But when used as a tool of energy management, it can help you make changes in operations or equipment that save energy dollars. Energy accounting can also help in budgeting, allocating resources for capital investment, and verifying the results of all of your energy management activities.

ENERGY AUDIT METHODOLOGY

Step 1 - Interview with Key Facility Personnel

During the initial audit, a meeting is scheduled between the auditor and all key operating personnel to kick off the project. The meeting agenda focuses on: audit objectives and scope of work, facility rules and regulations, roles and responsibilities of project team members, and description of scheduled project activities.

In addition to thee administrative issues, the discussion during this meeting seeks to establish: operating characteristics of the facility, energy system specifications, operating and maintenance procedures, preliminary areas of investigation, unusual operating constraints, anticipated future plant expansions or changes in product mix, and other concerns related to facility operations.

Step 2 - Facility Tour

After the initial meeting, a tour of the facility is arranged to observe the various operations first hand, focusing on the major energy consuming systems identified during the interview, including the architectural, lighting and power, mechanical, and process energy systems.

Step 3 - Document Review

During the initial visit and subsequent kick-off meeting, available facility documentation is reviewed with facility representatives. This documentation should include all available architectural and engineering plans, facility operation and maintenance procedures and logs, and utility bills for the previous three years. It should be noted that the available plans should represent "as-built" rather than "design" conditions. Otherwise, there may be some minor discrepancies between the systems evaluated as part of the audit and those actually installed at the facility.

Step 4 - Facility Inspection
After a thorough review of the construction and operating documentation, the major energy consuming processes in the facility are further investigated. Where appropriate, field measurements are collected to substantiate operating parameters.

Step 5 - Staff Interviews

Subsequent to the facility inspection, the audit team meets again with the facility staff to review preliminary findings and the recommendations being considered. Given that the objective of the audit is to identify projects that have high value to the customer, management input at this juncture helps establish the priorities that form the foundation of the energy audit. In addition, interviews were scheduled with key representatives designated by the facility as having information relevant to the energy audit. These representatives may include major energy consuming system service and maintenance contractors and utility representatives.

Step 6 - Utility Analysis

The utility analysis is a detailed review of energy bills from the previous 12 to 36 months. This should include all purchased energy, including electricity, natural gas, fuel oil, liquefied petroleum gas (LPG) and purchased steam, as well as any energy generated on site. If possible, energy data is obtained and reviewed prior to visiting the facility to insure that the site visit focuses on the most critical areas. Billing data reviewed includes energy usage, energy demand and utility rate structure. The utility data is normalized for changes in climate and facility operation and used as a baseline to compute projected energy savings for evaluated **ECM's (energy conservation measures)**.

Utilities generally offer a comprehensive portfolio of rate tariffs and riders that can be tailored to the energy consumption and demand of the end-user. In addition, with the advent of deregulation, energy can be purchased on contract from a number of third party marketers. Using energy consumption/demand characteristics revealed by a detailed analysis of recent utility bills, the optimum energy supply option is identified.

In addition, given the high cost of purchased energy it may be cost-effective to produce some of the facility's energy requirements on-site. Options may include: power generators for emergency power and peak-shaving, solar panels, wind power and cogeneration.

Step 7 - Identify/Evaluate Feasible ECMs (energy conservation measures)

Typically, an energy audit will uncover both major facility modifications requiring detailed economic analysis and minor operation modifications offering simple and/or quick paybacks. A list of major ECMs is developed for each of the major energy consuming systems (i.e., envelope, HVAC, lighting, power, and process). Based upon a final review of all information and data gathered about the facility, and based on the reactions obtained from the facility personnel at the conclusion of the field survey review, a finalized list of ECMs is developed and reviewed with the facility manager.

Step 8 - Economic Analysis

Data collected during the audit is processed and analyzed back in the office. The auditor builds models and simulations with software to reproduce field observations and develop a baseline against which to measure the energy savings potential of ECMs identified. Then the auditor calculates the implementation cost, energy savings and Life cycle cost analysis for each of the ECMs being investigated.

Step 9 - Prepare a Report Summarizing Audit Findings

The results of findings and recommendations are summarized in a final report. The report includes a description of the facilities and their operation, a discussion of all major energy consuming systems, a description of all recommended ECMs with their specific energy impact, implementation costs, benefits and payback. The report incorporates a summary of all the activities and effort performed throughout the project with specific conclusions and recommendations.

Step 10 - Review Recommendations with Facility Management

A formal presentation of the final recommendations is presented to facility management to supply them with sufficient data on benefits and costs to make a decision on which ECMs to be implemented.

TYPES OF ENERGY AUDITS

The term energy audit is commonly used to describe a broad spectrum of energy studies ranging from a quick walk-through of a facility to identify major problem areas to a comprehensive analysis of the implications of alternative energy efficiency measures sufficient to satisfy the financial criteria of sophisticated investors. Three common audit programs are described in more detail below, although the actual tasks performed and level of effort may vary with the consultant providing services under these broad headings. The only way to insure that a proposed audit will meet your specific needs is to spell out those requirements in a detailed scope of work. Taking the time to prepare a formal solicitation will also assure the building owner of receiving competitive and comparable proposals.

Preliminary Audit (Walk Through Audit)

The preliminary audit alternatively called a simple audit, screening audit or walk-through audit, is the simplest and quickest type of audit. It involves minimal interviews with site operating personnel, a brief review of facility utility bills and other operating data, and a walk-through of the facility to become familiar with the building operation and identify glaring areas of energy waste or inefficiency.

Typically, only major problem areas will be uncovered during this type of audit. Corrective measures are briefly described, and quick estimates of implementation cost, potential operating cost savings, and simple payback periods are provided. This level of detail, while not sufficient for reaching a final decision on implementing proposed measures, is adequate to prioritize energy efficiency projects and determine the need for a more detailed audit.

General Audit (Modified Audit)

The general audit alternatively called a mini-audit, site energy audit or complete site energy audit expands on the preliminary audit described above by collecting more detailed information about facility operation and performing a more detailed evaluation of energy conservation measures identified. Utility bills are collected for a 12 to 36 month period to allow the auditor to evaluate the facility's energy/demand rate structures, and energy usage profiles. Additional metering of specific energy-consuming systems is often performed to supplement utility data. In-depth interviews with facility operating personnel are conducted to provide a better understanding of major energy consuming systems as well as insight into variations in daily and annual energy consumption and demand.

This type of audit will be able to identify all energy conservation measures appropriate for the facility given its operating parameters. A detailed financial analysis is performed for each measure based on detailed implementation cost estimates, site-specific operating cost savings, and the customer's investment criteria. Sufficient detail is provided to justify project implementation.

Investment-Grade Audit (or Full Audit)

In most corporate settings, upgrades to a facility's energy infrastructure must compete with non-energy related investments for capital funding. Both energy and non-energy investments are rated on a single set of financial criteria that generally stress the expected return on investment (ROI). The projected operating savings from the implementation of energy projects must be developed such that they provide a high level of confidence. In fact, investors often demand guaranteed savings.

The investment-grader audit alternatively called a comprehensive audit, detailed audit, maxi audit, or technical analysis audit, expands on the general audit described above by providing a dynamic model of energy use characteristics of both the existing facility and all energy conservation measures identified. The building model is calibrated against actual utility data to provide a realistic baseline against which to compute operating savings for proposed measures. Extensive attention is given to understanding not only the operating characteristics of all energy consuming systems, but also situations that cause load profile variations on both an annual and daily basis. Existing utility data is supplemented with sub metering of major energy consuming systems and monitoring of system operating characteristics.

The following pages provide checklist tips for energy efficiency for various equipment and facilities.

ENERGY AUDIT OF A FACILITY

The basic approach to conduct energy audit for any type of organization/facility/complex is same. Every facility has quite a large extent similar energy consuming equipment and machinery, such as, lighting, HVAC, motors, pumps, compressors, boilers for steam generation, etc. There is no doubt that depending on the nature of manufacturing unit, some equipment/process, such as, dryers, extrusion, ovens, furnaces, etc., would be there. Therefore this "how to" manual addresses most common energy consuming equipment/processes, which cut across the organization/facility.

Initiation

There are similarities and dissimilarities between office buildings, commercial buildings and hotels. Offices and commercial units normally work as per scheduled timings unlike hotels. The occupancy in offices are normally hundred percent where as hotel occupancy varies season-to-season, day-to-day, and at times hour-to-hour.

Energy accounting and energy audit help achieve lower energy cost without compromising on the quality of service. In fact such an attempt would invariably lead to better service to the customers.

The following steps are important to derive maximum benefit from energy audit.

- **Track and compare the energy performance.**

  Understanding the relative energy performance can help prioritize investments in energy projects.

- **Review utility rate structure and identify load profile.**

  Chart monthly and hourly energy use to identify energy spikes that may raise the overall cost of energy due to peak demand charges. Consider installing meters that measure energy usage for major energy systems.

- **Have a written energy management plan.**

  Key components of plan should include energy forecasting and procurement, facility audits, financial analysis, integrated building upgrades, equipment purchasing, new construction, and preventive maintenance.

- **What are the annual energy costs and savings opportunities and what does that represent in terms of sales revenue?**

  Demonstrate how investments in energy performance affect key business metrics such as shareholder value and contribute to the overall performance of the company.

- **Get the staff educated and trained on how to keep tab on energy consumption and how to look out for energy saving opportunities.**

  There are a number of organizations providing training and ensure that the staff gets enough opportunities to undergo regular training outside and in-house both.

- **Have a preventive maintenance schedule that reduces wasted energy.**

  Consider such preventive measures as changing air filters, checking temperature settings, adjusting equipment operation schedules, and cleaning light fixtures.

- **Are occupancy sensors, timers, and energy efficient fixtures used to control lighting consumption?**

  Install electronic ballasts, T-8 lamps, compact fluorescent lights, and LED exit signs. Use occupancy sensors and programmable timing controls in intermittently used areas.

- **Try to reduce building loads as much as possible.**

  Using energy-efficient equipment and building technologies will reduce building loads, thus lowering electric, heating, and cooling bills and increasing occupant comfort. Part of the strategy should include purchasing energy efficient equipment such as televisions, computers, copiers, or fax machines.

- **Use HVAC controls to maximize energy savings.**

  Consider using programmable thermostats, motion detectors, and other controls to reduce heating and cooling needs in unoccupied visitors room/guestrooms and common areas.

- **Check whether HVAC system right-sized to meet heating and cooling loads?**

  Capitalize on the heating, cooling, and electrical load reductions realized through previous upgrades by allocating the funding to reevaluate heating and cooling loads and HVAC systems for possible downsizing.

- **Steam generation and utilization.**

  Consider reducing steam pressure for process heat utilization. This would help in conserving fuel. Ensure maximum condensate recovery and other measures to reduce energy consumption.

These are only a few of the many practices that can help save energy. The way to achieve these is to tackle equipment by equipment.

ENERGY AUDIT OF A UNIT/ COMPLEX – Example of Possible Interventions

The following facilities have been covered in this document:

1. Lighting
2. HVAC
3. Motors
4. Boilers
5. Water

1. Lighting

Selection off High Efficiency Lamps and Luminaires

Details of common types of lamps are summarized below. From this list, it is possible to identify energy saving potential for lamps by replacing with more efficient types.

Table 1.1: Information on Commonly Used Lamps

Lamp Type	Lamp Rating in Watts (Total Power including ballast losses in Watts)	Efficacy (including ballast losses, where applicable) Lumens/Watt	Color Rendering Index	Lamp Life
General Lighting Service (GLS) (Incandescent bulbs)	15,25,40,60,75,100,150,200, 300,500 (no ballast)	8 to 17	100	1000
Tungsten Halogen (Single ended)	75,100,150,500,1000,2000 (no ballast)	13 to 25	100	2000
Tungsten Halogen (Double ended)	200,300,500,750,1000,1500, 2000 (no ballast)	16 to 23	100	2000
Fluorescent Tube lights (Argon filled)	20,40,65 (32,51,79)	31 to 58	67 to 77	5000
Fluorescent Tube lights (Krypton filled)	18,36,58 (29,46,70)	38 to 64	67 to 77	5000
Compact Fluorescent Lamps (CFLs) (without prismatic envelope)	5, 7, 9,11,18,24,36 (8,12,13,15,28,32,45)	26 to 64	85	8000
Compact Fluorescent Lamps (CFLs) (with prismatic envelope)	9,13,18,25 (9,13,18,25) i.e. rating is inclusive of ballast cons.	48 to 50	85	8000
Mercury Blended Lamps	160 (internal ballast, rating is inclusive of ballast consumption)	18	50	5000
High Pressure Mercury Vapour (HPMV)	80,125,250,400,1000,2000 (93,137,271,424,1040,2085)	38 to 53	45	5000
Metal Halide Lamps (Single ended)	250,400,1000,2000 (268,427,1040,2105)	51 to 79	70	8000
Metal Halide Lamps (Double ended)	70,150,250 (81,170,276)	62 to 72	70	8000
High Pressure Sodium Vapour Lamps (HPSV)	70,150,250,400,1000 (81,170,276,431,1060)	69 to 108	25 to 60	>12000
Low Pressure Sodium Vapour Lamps (LPSV)	35,55,135 (48,68,159)	90 to 133	--	>12000

The following examples of lamp replacements are common.

- ***Installation of metal halide lamps in place of mercury / sodium vapor lamps***

  Metal halide lamps provide high color rendering index when compared with mercury & sodium vapor lamps. These lamps offer efficient white light. Hence, metal halide is the choice for color critical applications where, higher illumination levels are required. These lamps are highly suitable for applications such as assembly line, inspection areas, painting shops, etc. It is recommended to install metal halide lamps where color rendering is more critical.

- ***Installation of High Pressure Sodium Vapor (HPSV) lamps for applications where color rendering is not critical***

  High pressure sodium vapor (HPSV) lamps offer more efficacies. But the color rendering property of HPSV is very low. Hence, it is recommended to install HPSV lamps for applications such street lighting, yard lighting, etc.

- ***Installation of LED panel indicator lamps in place of filament lamps.***

Panel indicator lamps are used widely in industries for monitoring, fault indication, signaling, etc. The LEDs have the following merits over the filament lamps.

1. Lesser power consumption (Less than 1 W/lamp)
2. Withstand high voltage fluctuation in power supply.
3. Longer operating life (more than 1,00,000 hours)

The types of lamps used depends on the mounting height, color rendering may also be a guiding factor. Table below summarizes the replacement possibilities with the potential savings.

Table 1.2: Savings by Use of More Efficient Lamps

Existing Lamp	Replace by	Potential Energy Savings, %
GLS (Incandescent)	Compact Fluorescent Lamp (CFL)	38 to 75
	High Pressure Mercury Vapour (HPMV)	45 to 54
	Metal Halide	66
	High Pressure Sodium Vapour (HPSV)	66 to 73
Standard Tube light (Argon)	Slim Tube light (Krypton)	9 to 11
Tungsten Halogen	Tube light (Krypton)	31 to 61
	High Pressure Mercury Vapour (HPMV)	54 to 61
	Metal Halide	48 to 73
	High Pressure Sodium Vapour (HPSV)	48 to 84
Mercury Blended Lamp	High Pressure Mercury Vapour (HPMV)	41
High Pressure Mercury Vapour (HPMV)	Metal Halide	37
	High Pressure Sodium Vapour (HPSV)	34 to 57
	Low Pressure Sodium Vapour (LPSV)	62
Metal Halide	High Pressure Sodium Vapour (HPSV)	35
	Low Pressure Sodium Vapour (LPSV)	42
High Pressure Sodium Vapour (HPSV)	Low Pressure Sodium Vapour (LPSV)	42

Reduction of Lighting Feeder Voltage

Fig. 1.1 below shows the effect of variation of voltage on light output and power consumption for fluorescent tube lights. Similar variations are observed on other gas discharge lamps like mercury vapor lamps, metal halide lamps and sodium vapor lamps; table 1.2 summarizes the effects. Hence reduction in lighting feeder voltage can save energy, provided the drop in light output is acceptable. In many areas, nighttime grid voltages are higher than normal; hence reduction in voltage can save energy and also provide the rated light output. Some manufacturers are supplying reactors and transformers as standard products. A large number of industries have used these devices and have reported saving to the tune of 5% to 15%. Industries having a problem of higher nighttime voltage can get an additional benefit of reduced premature lamp failures.

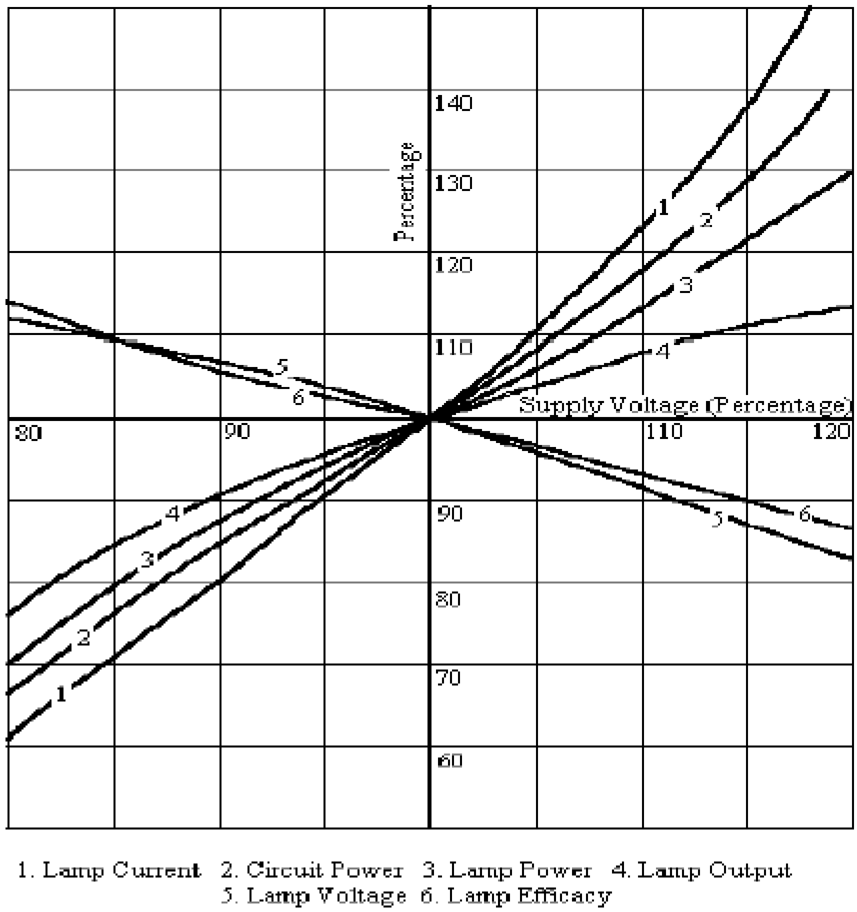

Figure 1.1: Effect of Voltage Variation on Fluorescent Tube light Parameters

Table 1.3: Variation in Light Output and Power Consumption

Particulars	10% lower voltage	10% higher voltage
Fluorescent lamps		
Light output	Decreases by 9 %	Increases by 8 %
Power input	Decreases by 15 %	Increases by 8 1%
HPMV lamps		
Light output	Decreases by 20 %	Increases by 20 %
Power input	Decreases by 16 %	Increases by 17 %
Mercury Blended lamps		
Light output	Decreases by 24 %	Increases by 30 %
Power input	Decreases by 20 %	Increases by 20 %
Metal Halide lamps		
Light output	Decreases by 30 %	Increases by 30 %
Power input	Decreases by 20 %	Increases by 20 %
HPSV lamps		
Light output	Decreases by 28 %	Increases by 30 %
Power input	Decreases by 20 %	Increases by 26 %
LPSV lamps		
Light output	Decreases by 4 %	Decreases by 2 %
Power input	Decreases by 8 %	Increases by 3 %

Electronic Ballasts

Conventional electromagnetic ballasts (chokes) are used to provide higher voltage to start the tube light and subsequently limit the current during normal operation. Electronic ballasts are oscillators that convert the supply frequency to about 20,000 Hz to 30,000 Hz. The losses in electronic ballasts for tube lights are only about 1 Watt, in place of 10 to 15 Watts in standard electromagnetic chokes. Table 1.4 shows the approximate savings by use of electronic ballasts.

Table 1.4: Savings by use of Electronic Ballasts

Type of Lamp	With Conventional Electromagnetic ballast	With Electronic Ballast	Power Savings, Watts
40W Tube light	51	35	16
35W Low Pressure Sodium	48	32	16
70W High Pressure Sodium	81	75	6

A good number of industries have installed electronic ballasts for tube lights in large numbers. The operation is reliable, provided the ballasts are purchased from established manufacturers. Electronic ballasts have also been developed for 20W and 65W fluorescent tube lights, 9W & 11W CFLs, 35W LPSV lamps and 70W HPSV lamps. These are now commercially available.

Low Loss Electromagnetic Chokes for Tube Lights

The loss in standard electromagnetic choke of a tube light is likely to be 10 to 15 Watts. Use of low loss electromagnetic chokes can save about 8 to 10 Watts per tube light. The saving is due to the use of more copper and low loss steel laminations in the choke, leading to lower losses. A number of industries have implemented this measure.

Timers,, Twilight Switches & Occupancy Sensors

Automatic control for switching off unnecessary lights can lead to good energy savings.

Simple timers or programmable timers can be used for this purpose. The timings may have to change, once in about two months, depending upon the season. Use of timers is a very reliable method of control. Twilight switches can be used to switch the lighting depending on the availability of daylight. Care should be taken to ensure that the sensor is installed in a place, which is free from shadows, light beams of vehicles and interference from birds. Dimmers can also be used in association with photo-control; however, electronic dimmers normally available in India are suitable only for dimming incandescent lamps. Dimming of fluorescent tube lights is possible, if these are operated with electronic ballasts; these can be dimmed using motorized autotransformers or electronic dimmers (suitable for dimming fluorescent lamps; presently, these have to be imported).

Infrared and Ultrasonic occupancy sensors can be used to control lighting in cabins as well as in large offices. Simple infrared occupancy sensors are now available. However ultrasonic occupancy sensors have to be imported. It may be noted that more sophisticated occupancy sensors used abroad have a combination of both infrared and ultrasonic detection; these sensors incorporate a microprocessor in each unit that continuously monitors the sensors, adjusting the sensitivity levels to optimize performance. The microprocessor is programmed to memories the static and changing features of its environment; this ensures that the signals received from repetitive heat and motion equipment like fans is filtered out.

In developed countries, the concept of tube light fixtures with in-built electronic ballast, photo-controlled dimmer and occupancy sensor is being promoted as a package.

The following control methodologies are useful.

General areas

- Where day lighting is available, provide day lighting controls. Use continuous dimming for spaces with minor motion activity such as reading, writing, and conferencing. Use stepped dimming (on/off switching) for spaces with major motion activity such as walking and shelf stocking.

- Always mount ultrasonic occupancy sensors at least 6 to 8 ft away from HVAC ducts on vibration free surfaces and place so there is no detection out the door or opening of the space.

- In spaces of high occupant ownership such as private offices and conference rooms, always include switches for manual override control of the lighting.

- If there is concern that lighting could be turned off automatically or manually when people are still in the space, put in night lighting for safe egress.

- Many lighting control devices have specific voltage and load ratings requirements. Be sure to specify the device model that matches the correct voltage and load rating for the application.

Conference Rooms

- Use dual technology occupancy sensors in larger conference rooms for optimal detection of both small hand motion and larger body movement.

- Ceiling or corner-mounted passive infrared occupancy sensors are used for medium and small conference rooms.

- Always include switches that provide manual override control of the lighting.

Cubicles

- Control plug loads such as task lighting, computer monitors, portable fans and heaters with an occupancy sensor controlled plug strip.

- Mount personal occupancy sensor beneath binder bin or desk and position so that it cannot detect motion outside cubicle area.

Restrooms

- Use ceiling mounted ultrasonic sensors for restrooms with stalls. Exterior Lighting Control

- Use a lighting control panel with time clock and photocell to control exterior lighting to turn on at dusk and off at dawn and turn non-security lighting off earlier in the evening for energy savings.

T5 Fluorescent Tube Light

The Fluorescent tube lights in use presently in Cyprus are of the T12 (40w) and T8 (36W). T12 implies that the tube diameter is 12/8” (33.8mm), T8 implies diameter of 8/8” (26mm) and T5 implies diameter of 5/8” (16mm). This means that the T5 lamp is slimmer than the 36W slim tube light. The advantage of the T5 lamps is that due to its small diameter, luminaire efficiencies can be improved by about 5%. However, these lamps are about 50mm shorter in length than T12 and T8 lamps, which implies that the existing luminaires cannot be used. In addition, T5 lamp can be operated only with electronic ballast. These lamps are available abroad in ratings of 14W, 21W, 28W and 35W. The efficiency of the 35W T5 lamp is about 104 lm/W (lamp only) and 95 lm/W (with electronic ballasts), while that of the 36W T8 lamp is about 100 lm/W (lamp only) and 89 lm/W (with electronic ballast). This may appear to be a small improvement of about 7%, but with the use of super-reflective aluminium luminaire of higher efficiency, T5 lamps can effect an overall efficiency improvement ranging from 11% to 30%. T5 lamps have a coating on the inside of the glass wall that stops mercury from being absorbed into the glass and the phosphors. This drastically reduces the need for mercury from about 15 milligrams to 3 milligrams per lamp. This may be advantageous in countries with strict waste disposal laws.

In Europe, the T5 lamps are being used in good numbers in place of 4 foot, 36W T8 lamps. Their shorter lengths permit integration in standard building modules. With new miniature ballasts, luminaires are light and flat, saving space and also resources used for their production. The U.S.A. has been slow in accepting this technology, as the 4 foot, T8 lamps consume only about 35 Watts. Secondly, the focus in the U.S.A. has generally been on better optic control, rather than on lamp efficiency.

Lighting Maintenance

Maintenance is vital to lighting efficiency. Light levels decrease over time because of aging lamps and dirt on fixtures, lamps and room surfaces. Together, these factors can reduce total illumination by 50 percent or more, while lights continue drawing full power. The following basic maintenance suggestions can help prevent this.

- Clean fixtures, lamps and lenses every 6 to 24 months by wiping off the dust.
- Replace lenses if they appear yellow.
- Clean or repaint small rooms every year and larger rooms every 2 to 3 years. Dirt collects on surfaces, which reduces the amount of light they reflect.
- Consider group re-lamping. Common lamps, especially incandescent and fluorescent lamps lose 20 percent to 30 percent of their light output over their service life. Many lighting experts recommend replacing all the lamps in a lighting system at once. This saves labor, keeps illumination high and avoids stressing any ballast with dying lamps.

Guiding Principles for Lighting

Principle

- The efficiency of a light source is indicated by luminous efficacy, lm/Watt. Manufacturers usually give this value after testing the lamps at laboratories. It is difficult to establish the luminous efficacy value of lamps at site conditions.
- All the light emitted by the lamp does not reach the work area. Some light is absorbed by the luminaire, walls, floors & roof etc. The illuminance

measured, in lumens/m2 i.e. lux, indicates how much light i.e. lumens is available per sq. meter of the measurement plane.

- Target luminous efficacy (lm/Watts) of the light source is the ratio of lumens that can be made available at the work plane under best luminous efficacy of source, room reflectance, mounting height and the power consumption of the lamp circuit. Ideally, the target luminous efficacy should be available on the work plane.

- However, over a period of time the light output from the lamp gets reduced, room surfaces becomes dull, luminaires becomes dirty and hence the light available on the work plane deviates from the target value. The ratio of the actual luminous efficacy on the work plane and the target luminous efficacy at the work plane is the Installed Load Efficacy Ratio (ILER).

- A second aspect of efficiency of utilization is to take into account, the light available at task and non-task areas. Usually for commercial areas, the recommended illuminance at the non-task areas is at least one-third of the average task illuminance, while keeping a minimum illuminance required at the horizontal plane to be 20 lux. From illuminance measurements the ratio of illuminance at non task areas and task areas can be estimated to understand whether the non-task illuminance level is more than required or not.

- Illuminance levels recommended at various work spaces are given in Table 1.5.

Pre-test Requirements

- Measurement of illuminance in an electrical lighting system should be done after dark. This is essential especially in outdoor installations. For indoor lighting, measurements with lights ON and Lights OFF technique can be followed provided the daylight variation is not too much and the survey time is not too long.

- In an installation of fluorescent discharge lamps, the lamps must be switched on at least 30 minutes before the measurement to allow for the lamps to be completely warmed up.

- In many situations, the measuring plane may not be specified or even non-existent. Hence it is necessary to define measurement height, typically 0.8 to 1 meter from the ground or

- Stray light from surrounding rooms, spaces and through external windows should be minimized by use of blinds, curtains, etc.

- Any automatic lighting control or daylight linked controls should be set such that the output of the lamps is at full power and will not vary during the tests.

All lighting in the area that would normally illuminate the area test grid should be operating.

- It is convenient to have a second person recording the readings called out by the person moving the photocell.

Precautions

Care must be taken not to shadow the photocell when making measurements.

In single-phase supply of power for lighting in an area, when measuring lamp circuit power using a clamp on type meter, measure the power preferably on the phase conductor. If current/power is measured on the main cable, which encloses both phase and neutral conductors, the current and power will indicate zero.

Instruments and Methods of Measurements

Measurement/estimation of parameters

The measurement of following parameters is required.

- Illuminance
- Power input
- Length & width of room, Mounting height

Illuminance measurements

Instruments

Lux meters corrected for V-lambda should be used for measurement of illuminance. The accuracy of 5% and suitable range up to 10000 lux should be used. Usually lux meters are calibrated under the “standard light tungsten source of 2856 K” precisely. If these are used under different type of light source, the following correction factor is used on the measured value of lux.

Table 3: Correction factors for lux meters

Light source	Correction factor
Mercury Lamp	X 1.05
Fluorescent Lamp	X 0.99
Sodium Lamp	X 1.11
Daylight	X 0.95

The above corrections factors are dependent on the type of lux meter used. Actual figures for the type of instrument used for measurement will be available in the calibration certificate.

Accuracies of readings should be ensured by

- Using accurate illuminance meters for measurements

- Sufficient number and arrangement of measurement points within the interior
- Proper positioning of illuminance meter
- Ensuring that no obstructions /reflections from surfaces affect measurement.

Guidelines for Identifying Energy Saving Opportunities

- Use as much natural daylight as possible by use of translucent roofing sheets.

- Use day lighting effectively by locating workstations requiring good illuminance near the windows.

- Minimize illuminance in non- task areas by reducing the wattage of lamps or number of fittings

- Avoid use of incandescent/tungsten filament lamps. The power consumed by these lamps is 80% more than the fluorescent lamps (discharge) for same lumen output.

- Use electronic ballasts in place of conventional ballast for fluorescent lamps.

- Task lighting saves energy, utilize it whenever possible.

- All surfaces absorb light to some degree and lower their reflectance. Light colored surfaces are more efficient and need to be regularly painted or washed in order to ensure economical use of light.

- Maintenance is very important factor. Evaluate present lighting maintenance program and revise it as necessary to provide the most efficient use of lighting system.

- Clean luminaries, ceilings, walls, lamps etc. on a regular basis.

- Controls are very effective for reducing lighting cost.

- Install switching or dimmer controls to provide flexibility when spaces are used for multiple purposes and require different amounts of illumination for various activities.

- Switching arrangements should permit luminaries or rows of luminaires near natural light sources like windows or roof lights to be controlled separately.

- Separate lighting feeder and maintain the feeder at permissible voltages by using transformers.

2. HVAC

Minimizing Refrigeration & Air-conditioning

Operating at Higher Evaporator Temperature

Table 2.1 shows the variation of refrigeration capacity, power consumption and specific power consumption for a particular vapor compression system with evaporator refrigerant gas temperature. It may be observed that higher the temperature, higher the system capacity, higher the power input and lower the specific power consumption (kW/TR). This clearly indicates that the cooling effect increases in greater proportion than the power consumption, thus the system will cool faster and shut off.

The approximate thumb rule is that for every 1°C higher temperature in the evaporator, the specific power consumption will decrease by about 2 to 3%.

Table 2.1: Effect of Evaporator and Condenser Temperatures on Refrigeration Machine Performance

Evaporator Temperature °C		Condenser Temperatures °C			
		+35	+40	+45	+50
+5	Capacity (TR)	151	143	135	127
	Power cons. (kW)	94	102.7	110.6	117.8
	Sp. Power (kW/TR)	0.62	0.72	0.82	0.93
0	Capacity (TR)	129	118	111	104
	Power cons. (kW)	90	96.8	103	108.9
	Sp. Power (kW/TR)	0.70	0.82	0.93	1.05
-5	Capacity (TR)	103	96	90	84
	Power cons. (kW)	84.2	89.6	94.7	99.4
	Sp. Power (kW/TR)	0.82	0.93	1.05	1.19

Increasing the Chilled Water Temperature Set Point

The rationale behind temperature settings for process applications needs to be reviewed, keeping the present high energy costs in view. The aim is to avoid unnecessary supercooling, without affecting production, quality and safety. Increasing energy costs have forced many industries to experiment and stabilize operation at higher temperatures.

Improve Air Distribution and Circulation in Air Conditioned Rooms

In some air-conditioning systems, lower temperatures are set to over come problems of poor air distribution; making changes in ducting may be a more economical solution than permanently paying higher energy bills. In air-conditioned spaces, use of circulation fans can provide apparent comfort and help raise the room temperature settings to about 26°C instead of 24°C. Quiet fans can be concealed behind suspended grid to ensure that the décor is not affected. The reduction in energy consumption in the refrigeration machine will be significantly more than that consumed by the circulation fans.

Accurate Measurement and Control of Temperature

Most vapor compression machines use superheat sensing expansion valves, which does not give accurate temperature control especially when the compressor is operating at part load, resulting in significant temperature fluctuations. When the refrigeration system's cooling capacity is significantly more than the actual cooling load, expansion valve control based on superheat sensing often leads to super-cooling, resulting in an energy penalty due to unnecessarily lower temperature and also lower COP at lower temperatures.

This can be avoided by the use of electronic expansion valves, which are modulating valves that operate based on electronic sensing of the end-use temperature. A Mumbai based company has invented a new temperature controller that senses the temperature of the return air/water/brine and controls the superheat expansion valve by heating or cooling, as necessary, to give very accurate temperature control. This controller can be conveniently retrofitted on the existing superheat sensing system i.e. with out disturbing the existing expansion valve control system. This technology is already commercialized. Some industries and commercial buildings have reported energy savings along with good temperature control between +/-1°C. Please see case study.

Reduction in Heat Loads

<u>Keep Unnecessary Heat Loads Out</u>

Unnecessary heat loads may be kept outside air-conditioned spaces. Often, laboratory ovens/furnaces are kept in air-conditioned spaces. Such practices may be avoided. Provide dedicated external air supply and exhaust to kitchens, cleaning rooms, combustion equipment etc. to prevent negative pressure and entry of conditioned air from near by rooms. In cold stores, idle operation of forklift trucks should be avoided.

<u>Use False Ceilings</u>

Air-conditioning of unnecessary space wastes energy. In rooms with very high ceiling, provision of false ceiling with return air ducts can reduce the air-conditioning load. Relocate air diffusers to optimum heights in areas with high ceilings.
<u>Use Small Control Panel Coolers</u>

CNC machine shops, Telecom switching rooms etc. are air-conditioned. As cooling is required only for the control panels, use of small power panel coolers and hydraulic oil coolers (0.1 to 0.33 TR are available) can make the whole centralized air-conditioning redundant and save energy.

Use Pre-Fabricated, Modular Cold Storage Units

Cold stores should be designed with collapsible insulated partitions so that the space can be expanded or contracted as per the stored product volumes. The idea is to match product volumes and avoid unnecessary cooling of space and reduce losses. Modular cold store designs are commercially available.

Cycle Evaporator Fans in Cold Stores

In cold stores that remain shut for long periods, the heat load of the fans can be the major load. After attainment of temperature, refrigerant flow in evaporator fan-coils units and fan operation can be cycled on and off, using a programmable controller. This will reduce the heat load of fans and save energy (see case study).

Minimizing Heat Ingress

Air Conditioned Rooms/Halls

Table 2.2 shows the comparison of heat ingress through identically sized open doors of air conditioned room.

Table 2.2 Heat Ingress into Air-conditioned Space through Open Doors
(Door Size: 2m x 1m;
Ambient Condition: 30°C & 60% Relative Humidity)

	Normal Air-conditioned room	Cold Storage
Room temperature, °C	24	-16
Room relative humidity, %	60	90
Additional heat load, TR	2.5	25

Check and Maintain Thermal Insulation

Repair damaged insulation after regular checks. Insulate any hot or cold surfaces. Replace wet insulation. Insulate HVAC ducts running outside and through unoccupied spaces. Provide under-deck insulation on the ceiling of the top most floors of airconditioned buildings.

Insulate Pipe Fittings

Generally, chilled water/brine tanks, pipe lines and end-use equipment in the industry are well insulated. However, valves, flanges etc. are often left uninsulated. With rising energy costs, it pays to insulate pipe flanges, valves, chilled water & brine pumps etc. also (fig. 2.1). Pre-formed insulation or ‘home-made’ box type insulation can be used.

Fig.2.1: Well thermally insulated chilled water system

Use Landscaping to the Reduce Solar Heat Load

At the time of design of the building, fountains and water flow can be used provide evaporative cooling and act as heat sinks. Trees may be grown around buildings to reduce the heat ingress through windows and also reduce glare.

Reduce Excessive Use of Glass on Buildings

Modern commercial buildings (fig. 2.2) use glass facades and/or large window area resulting in large solar heat gain and heat transmission. This architecture is not suitable for Cyprus as it increases the air conditioning load for about six months in a year. In existing building, the possibility of replacing the glass panes with laminated insulation boards may be resorted to. Glass facades, if desired, can be provided in the form of a glass curtain external to a convention wall with necessary window area.

Fig.2.5: Typical Modern Building with Glass Façade

Use Glass with Low Solar Heat Gain Coefficient (SHGC) and Thermal Conductivity

Table 2.3 shows the SHGC, Thermal Conductivity and Daylight Transmittance for different types glass panes. Use of glass with low SHGC and thermal conductivity is recommended. Daylight transmittance is important, if electric lighting (another heat load) has to be minimized.

Table 2.3 Properties of Different Types of Window Glass

Product	Solar Heat Gain Coefficient (SHGC)	Thermal Conductivity	Daylight Transmittance
Clear Glass	0.72	3.16	79
Body Tinted Glass	0.45	3.24	65
Hard Coated Solar Control Glass	0.26	3.27	24
Soft Coated Solar Control Glass	0.18	3.08	15
Low Emissivity Glass	0.56	2.33	61
Solar Control + Low Emissivity Glass	0.23	1.77	41

<u>Use Low Conductivity Window Frames</u>

Consider the use of plastic window frames in place of steel and aluminium frames. This can reduce the heat ingress by conduction.

<u>Use Doors, Air-Curtains, PVC Strip Curtains for Air Conditioned Spaces</u>

Add vestibules or revolving door or self-closing doors to primary exterior doors. Air curtains and/or PVC strip curtains are recommended for air-conditioned spaces with heavy traffic of people or pallet trucks. Use intermediate doors in stairways and vertical passages to minimize building stack effect.

Reducing Ventilation Air Requirement by Ozone Dosing

The oxygen in the fresh air oxidizes the Volatile Organic Compounds (VOC) and odors. The air also dilutes the CO2. The minimum ventilation requirement is 15 cfm per person in a non-smoking room and 30 cfm per person if smoking is permitted. The load on the air conditioning system increases with ventilation. Use of controlled injection of ozone can help reduce the quantity of fresh air. Ozone is a powerful oxidant, which removes odor, VOC and even fungi by oxidation. This reduces the oxygen requirement in the form of ventilation and air is mainly required for diluting CO2. This is a much smaller requirement, thus fresh air can be modulated rationally down to 5 cfm or less per person. However, if residual concentration of ozone exceeds limits, ozone is a toxic gas. The ASHRAE limit is 0.05 ppm. A plate type corona generator in the air duct is recommended along with an auto VOC controller.

Using Favorable Ambient Conditions

<u>Use Cooling Tower Water Directly for Cooling in Winter</u>

In locations with dry climate, the winter dry bulb (air) and wet bulb (water) temperatures are very low, especially at nights. During winter, cooling towers may be able to give temperatures of 8° to 12°C. Plate heat exchangers can be used to transfer the heat load directly to the cooling tower, bypassing the chillers and shutting off the compressors or absorption machines. This system is used in very cold countries to prevent ice build-up in cooling towers.

Design New Air-conditioning Systems with Facility for 100% Fresh Air during Winter

In air-conditioned systems with centralized AHUs, fresh air and exhaust air ducts can be provided with dampers (and blowers, if necessary) to mix fresh air or use 100% fresh, filtered air, depending on the ambient conditions. These systems should also have the facility to for exhaust the stale, warm air. Such air conditioning systems can be fitted with enthalpy sensors and motorized dampers to have maximized the use of ambient fresh air.

The normal energy consumption of the air conditioning system may be comparatively less in winter, but even this can be avoided if the system design incorporates the facility for using favorable ambient conditions.

Fresh air systems can also be easily retrofitted in most central air conditioning systems with air handling rooms.

Energy Saving Opportunities in Normal Operation

Use Building Thermal Inertia in Air Conditioning for Early Switch Off

Once the entire building in cool, it takes a few hours to again come back to normal temperature. This building thermal lag can be used to minimize HVAC equipment operating time by shutting the air-conditioning system half hour or one hour before closing time.

Put HVAC Window Air Conditioners and Split Units on Timer or Occupancy Sensing Control

Window air conditioners and Split air conditioners installed for office cabins may operate unnecessarily for long time without cabins being occupied. The use of timers or infra-red occupancy sensors can help switch of these machines automatically.

Interlock Fan Coil Units in Hotels with Door Lock or Master Switch

In hotels, unnecessary operation of Fan Coil Units can be prevented by providing an interlock with the door locking system or by switching control at the reception desk. The fan of the fan-coil unit should get switched off or go to low speed mode and the chilled water flow should be cut off by a solenoid valve. This can reduce the air-conditioning load in business hotels, during day time, when rooms are mostly not occupied.

Improve Utilization Of Outside Air.

In systems with facility for using fresh air, maximize the use of fresh air when ambient conditions are favorable.

Install a Chiller Control System to Co-Ordinate Multiple Chillers.

Study part-load characteristics and cycling costs to determine the most efficient mode for operating multiple chillers. Run the chillers with lowest operating costs to serve the base load. Link Chiller control system to the Building Automation System to maximize savings.

Permit Lower Condenser Pressures during Favorable Ambient Conditions

Favorable ambient conditions reduce cooling air or cooling water temperatures, which will reduce condensing temperatures and pressures, thus reducing the compressor power. The control systems may set to allow the machines to operate at lower condenser pressure.

Defrosting

In cold stores, accumulation of frost on the evaporator tube reduces the air flow rate and hence the heat transfer rate significantly. The most widely used methods for defrosting are:

1. Shutting down the compressor, keeping the fan running and allowing the space heat to melt the frost.
2. Using out side warm air to melt the frost after isolating the coil from the cold room.
3. Using electric resistance heaters in thermal contact with the coil,
4. Bypass the condenser and let the hot gas into the evaporator to melt the frost,
5. Spray water on the coils to melt the frost.

The most popular method is the hot gas defrost, this is also relatively less expensive as the heat is a by-product of the refrigeration system. Water spray defrosting is used when quick defrosting is required in production mode, where quick return to production is essential. Electric defrosting is very expensive operationally due to the high cost of electricity.

Irrespective of method, regular defrosting is an essential to maintain the heat transfer efficacy in the evaporator. The frequency of defrosting would depend on the rate of frost build-up, which again depends on the materials being stored. “Defrost on demand” control, which initiates defrost as per requirement rather than by a timer, can save energy where the freezing moisture load is variable.

Match the Refrigeration System Capacity to the Actual Requirement

Most of the refrigeration systems are oversized. Close matching of compressor capacity to the actual requirement will automatically raise the evaporator temperature and pressure, improved heat transfer efficacy and lower energy consumption in the compressor. This can be achieved by switching off some machines or by varying the speed of the compressor. For steady refrigeration loads, the speed can be changed by changing the pulley ratio. For fluctuating refrigeration loads, the use of variable speed drives may be required.

Maintenance to Ensure Energy Efficient Operation

Temperature Settings

Regularly check control settings as these can drift over a period of time. Instrumentation should have the facility of programming and locking the settings with password protection.

Clean Fouled Heat Exchangers

Inefficient operation of refrigeration machines is usually due to fouling of condensers. This happens generally due to the absence of water treatment or poor water treatment practices. Scaling of condenser tubes reduces the heat transfer efficacy, increases the refrigerant temperature and pressure in the condenser, reduces the cooling capacity, increases the power consumption in the compressor. If this problem is ignored, it can also lead to tripping to the compressor on high discharge pressure. Chemical cleaning of heat exchangers is necessary to maintain the heat transfer efficacy. On-line monitoring and dosing systems are available for water treatment, this can ensure scale free operation on a continuous basis.

In the case of evaporative condensers, cleaning air side of condenser tubes helps in maintaining good heat transfer efficacy.

Air handling unit coil tube and fins should also be regularly cleaned externally.

Specify Appropriate Fouling Factors for Condensers

Fouling factors are considered in heat exchanger design to oversize the heat exchangers to offset the effect of fouling. However, equipment suppliers generally consider a fouling factor of 0.0005; a good water treatment program is required to contain fouling within this limit. Ordinary scale of $CaCO_3$ of only 0.6 mm is equivalent to a fouling factor of 0.002. Studies have shown that 0.6 mm scale can result in an energy loss of about 20%. Absence of water treatment programs or poorly managed water treatment programs can very easily lead to scales of this magnitude. Hence proper sizing of heat exchangers, based on realistic fouling factors, and a scientific water treatment program (based on regular water quality measurements) are essential to maintain efficiency of refrigeration systems.

Purging the Condenser of Air

Air and other non-condensible gases may enter a system through leaks in seals, gaskets or uncapped valves. Air may also be present because of imperfect evacuation before initial charging of the system or due to impurities in the refrigerant or oil.

The non-condensibles in condensers add partial pressure to the refrigerant about and thus increase the pressure against which the compressor has to work. The heat transfer coefficient also drops as the refrigerant has to diffuse through non-condensibles to the tube surface before condensing.

The methods used for air purging are

- Direct venting of the air-refrigerant mixture, which is a primitive manual technique
- A small compressor draws a sample of the refrigerant gas and compresses the mixture, condensing as much as possible of the refrigerant, and vents the vapor mixture that is now rich in non-condensibles
- A low temperature evaporator, in-built in the system, condenses most of the refrigerant from the refrigerant-air mixture drawn from the condenser or receiver and vents the non-condensibles. This method does not require a separate compressor and is used widely.

Purging of non-condensibles plays an important role in maintaining the efficiency of refrigeration machines.

Pumping Systems

Some of the methods of reducing the energy consumption is pumping systems are

- Increase fluid temperature differentials to reduce pumping rates. After a critical study of the requirement, this can be experimentally done by throttling of valves. Variable speed drives can be programmed to maintain constant temperature differentials across heat exchangers.
- Balance the system to minimize flows and reduce pump power requirements. In systems with hot and cold wells, the over flow from one to the other should be reduced to the bare minimum
- Use small booster pumps for small loads requiring higher pressures, instead of raising the entire flow to the high pressure.
- Use siphon effect to advantage: don't waste pumping head with a free fall return. This can be detected by measuring the pressure in the chilled water / brine / cooling water return lines near the discharge point.
- Operate pumps near their best efficiency point. Both throttling of valves as well as excessive circulation of flow may move the pump away from the best efficiency point, leading to significant drop in efficiency.
- Modify pumps to minimize throttling. This may involve change of impellers or pumps.
- Adapt to wide flow variation with variable speed drives or sequenced control of smaller units.
- Repair seals and packing to minimize water waste, especially chilled water.

<u>Fans/Blowers</u>

The following points are useful to reduce energy consumption in blowers and fans.

- Turn fans off when they are not needed.
- Clean screens, filters and fan blades regularly.
- Minimize fan speed.
- Check belt tension regularly.
- Eliminate ductwork air leaks.

Energy Saving in Low Relative Humidity Air Conditioning

Some industrial applications require that the relative humidity be strictly maintained at levels ranging from 25% to 45% or less with room air temperatures ranging from 18° to 24°C. The traditional method to achieve this end is to lower the air temperature to very low levels (say 6° to 8°C) to condense out more moisture, followed by heating of the cold air (using electric heaters or steam coils in the duct) to about 14° to 18°C to satisfy the specified room temperature and relative humidity conditions. However, there is double energy penalty being paid by the use of this system i.e. additional energy consumption in duct heaters and additional energy consumption in the compressors to dissipate this heat added in the duct.

Use of the above mentioned heat exchangers could transfer heat from the warm, return air at 24°C (say) to the cold air from the AHU at 8°C (say) thus totally eliminating the need for duct heaters. This saves the duct heating energy and also reduces the cooling load on the compressor. Use of these heat recovery heat exchangers have lead to savings ranging from 30% to 60% in air-conditioning energy consumption in some industries.

General Tips to Save Energy in Cooling Towers

- Control to the optimum temperature as determined from cooling tower and chiller performance data.
- Use two-speed or variable speed drives for cooling tower fan control if the fans are few. Stage the cooling tower fans with on-off control if there are many.
- Turn off unnecessary cooling tower fans when loads are reduced.
- Cover hot water basins (to minimize algae growth that contributes to fouling.
- Balance flow to cooling tower hot water basins.
- Periodically clean plugged cooling tower distribution nozzles.
- Install new nozzles to obtain a more uniform water pattern.
- Replace splash bars with self-extinguishing PVC cellular film fill.
- On old counterflow cooling towers, replace old spray type nozzles with new square spray ABS practically non-clogging nozzles.
- Replace slat type drift eliminators with low pressure drop, self extinguishing, PVC cellular units.
- Follow manufacturer’s recommended clearances around cooling towers and relocate or modify structures that interfere with the air intake or exhaust.
- Optimize cooling tower fan blade angle on a seasonal and/or load basis.
- Correct excessive and/or uneven fan blade tip clearance and poor fan balance.
- Use a velocity pressure recovery fan ring.

- Consider on-line water treatment.
- Restrict flows through large loads to design values.
- Shut off loads that are not in service.
- Take blow down water from return water header.
- Optimize blowdown flow rate.
- Send blowdown water to other uses or to the cheapest sewer to reduce effluent treatment load.
- Install interlocks to prevent fan operation when there is no water flow.

Recommended Measurements for Chiller Packages

Measurement/estimation of the following parameters should be done for the Chiller Package to estimate its performance.

Vapor Compression Chiller Package

a. Measurement of fluid (water, brine, air etc.) flow rate in evaporator.
b. Measurement of cooling air or cooling water flow rate, as applicable, in the condenser.
c. When the fluid being cooled is liquid, measurement of liquid temperature at the inlet and outlet of the evaporator.
d. When the fluid being cooled is air, measurement of dry bulb temperature and wet bulb temperatures of air at the inlet and outlet of the evaporator (normally called air handling unit).
e. For water-cooled condensers, water temperature at the inlet and outlet of the condenser.
f. For air-cooled condensers, dry bulb and wet bulb temperatures of the air at inlet and outlet.
g. Estimation of shaft power of compressor from electrical power input to the motor or engine fuel consumption rate or turbine steam flow rate.

Vapor Absorption Chiller Package

a. Measurement of fluid (water, brine, air etc.) flow rate in the evaporator.
b. Measurement of cooling water flow rate, as applicable, in the condenser.
c. Measurement of cooled fluid temperature at the inlet and outlet of the evaporator.
d. For water-cooled condensers, measurement of water temperature at the inlet and outlet of the condenser.
e. Measurement of steam mass flow rate for steam heated package.
f. Measurement of fuel flow rate for direct-fired package.

Temperature Measurements

Temperature measurements include the following:

a. Liquid temperature measurements at the inlet and outlet of the evaporator.
b. Air dry bulb and wet bulb measurements at the inlet and outlet of the evaporator.

c. Water temperature measurements at the cooling water inlet and outlet and de-superheater water inlet and outlet, where applicable.
d. Air dry bulb and wet bulb measurements at the inlet and outlet of the condenser.

Temperature Measuring Instruments

The inlet and outlet fluid temperatures may be measured with any of the following instruments:

a. Calibrated mercury in glass thermometer (bulb diameter not greater than 6.5 mm).
b. Calibrated thermocouple with calibrated indicator.
c. Calibrated electric resistance thermometer.

The measuring instruments should be duly calibrated. The least count for temperature indicating instruments should be 0.1°C.

Measurement Techniques

i. Use thermo-wells made of thin steel or brass tube welded or brazed to a hole pierced in the piping before and after the heat exchanger. The wells should be partly filled with a suitable fluid of sufficient quantity to cover the thermometer bulb. The thermo-well should extend into the pipe a distance of 100 mm or 1/3rd of the pipe diameter whichever is less.
ii. The measuring instruments used to measure temperature should be arranged so that they can be readily interchanged between inlet and outlet positions to improve accuracy. Under steady state conditions, to reduce error, the same temperature sensor and indicator may be used to measure the inlet and outlet temperature. At least three sequential measurements should be taken to ensure that the chiller is in steady state.
iii. In the absence of thermo-wells, direct temperature measurement can be attempted by leaking water or brine from the nipples with valves, if available (usually these are available for installation of pressure gauges). Care has to be taken to ensure that the nipple length is small and the leakage flow is large enough to reduce the error, due to temperature pick-up as the leaked fluid flows through the un-insulated nipple, to a negligible value. Measurement of temperature can be done by collecting the liquid in a small container and allowing the liquid to continuously overflow from the container by opening the valve sufficiently. However, the fluid should be leaked only for a few minutes to facilitate temperature measurement and not continuously. The quantity of fluid being leaked out should be negligibly small compared to the flow through the evaporator.

Liquid Flow Measurement

Liquid flow measurements include the following:

a. Liquid (water or brine) flow in the evaporator.
b. Water flow in water-cooled condenser.

Liquid Flow Rate Measuring Instruments / Methods

Liquid flow may be measured with any of the following instruments/methods:

a. Calibrated in-line liquid flow rate meter.
b. Volumetric measurements based on liquid levels from a calibrated tank.
c. Velocity measurement using Transit Time Ultrasonic flow meter. Measurement of pipe internal diameter using ultrasonic thickness guage or estimation of the same using standard tables for the particular class of pipe. Estimation of flow area from the pipe internal diameter. Estimation of the flow as the multiplication product of the velocity and flow area. In the case of ultrasonic flow meters, care may be taken to ensure that the error is less than 5%. (Use of Ultrasonic Meter requires a dry pipe surface, hence chilled water/brine pipe surfaces have to wipe dry, followed by quick fixing the probe).
d. Estimation of pump flow from discharge pressure, electrical power measurements, estimation of pump shaft power and co-relation with performance curves from test certificate or performance characteristics for the particular pump model. This method is valid only if one pump or a group of pumps are connected to a single chiller package. The error in flow estimation by this method can be 5 to 10% or even higher, especially when general pump model type performance characteristics are used to estimate the flow. This method is not recommended unless the use of inline or portable flow measuring instruments is ruled out due to site constraints.

Air Flow Rate Measuring Instruments / Methods

Air flow measurements include the following:

a. Air flow in the Air Handling Unit.
b. Air flow in air-cooled condenser.

Air Velocity Measuring Instruments

Air flow may be measured with any of the following instruments:

a. Vane Anemometer
b. Hot wire anemometer
c. Pitot tube

The measuring instruments should be duly calibrated. The least count for anemometers should be 0.1 m/s.

3. MOTORS

Electric motors are intrinsically very efficient. Their efficiencies vary from 85% to 95% for motors of sizes ranging from 10 HP to 500 HP. It is still possible to improve the efficiency of these motors by 1 to 4% by using more efficient motors. However, in the energy efficiency game, there are a number of other things also one should focus; more than just improving the efficiency of motors alone. In fact maximum electric energy is consumed in motors, which are used for various applications.

This "how to manual" will discuss mainly the energy efficiency related issues in selection and application of motors.

Proper Sizing of Motors

It is important to note that it is the load that determines how much power the motor draws. The size of the motor does not necessarily relate to the power being drawn. For example, a fan requiring 15 kW could be driven by a 15 kW motor; in which case, it is well matched. It could also be driven by a 30 kW motor, and although it would work, it would not be very efficient.

Motors are often oversized because of:

1. Uncertainty about load;
2. Allowance for load growth,
3. Rounding up to the next size;
4. Availability;

Because motor efficiency curves vary substantially from motor to motor, it is difficult to make a blanket statement as to which motors should be downsized. In general, if the motor operates at 40% of its rated load or less, it is a strong candidate for downsizing. This is especially true in cases where the motor load does not vary much. If you have a 100 horsepower motor that is typically operating at 35 horsepower, for example, but periodically is required to operate at 90 horsepower, it may not make sense to downsize the motor. If your motor operates at 50- 100% of its rated load, it is probably not a good candidate for downsizing, since it is operating near its peak efficiency.

It often makes sense to replace oversized motors even if the existing motor has not failed. Note energy costs for a motor over the course of a year can be up to five times the cost of a new motor. This is especially true in cases where the motor is operating at a lower efficiency level due to over sizing.

Of course, there are benefits to over sizing motors in certain cases that should not be overlooked when determining what the proper motor is for a given application. In addition to providing capacity for future expansion, oversized motors can accommodate unanticipated high loads and are likely to start and operate more readily in under voltage conditions. These advantages can normally be achieved, however, with a modest over sizing margin.

The efficiency of motors operating at loads below 40% is likely to be poor and energy savings are possible by replacing these with properly sized motors.

Drive Transmission

Belt Drives

Direct drive is the most preferred option as it avoids transmission loss.

V-belt drives may have an efficiency of 85% to 90%; efficiencies of loose belts may be lower. Modern synthetic, flat belts have an efficiency of 96% to 98%. The losses in V-belts are higher as the belt wedges-in and wedges-out of the pulley grooves. Many users have achieved 5% to 8% savings by replacement of V-belts by flat belts. Synthetic flat belt technology has matured and is a preferred option, especially for new belt driven equipment.

For retrofit applications, expert advice should be taken in the selection of new flat belt and pulleys widths to avoid failures. Care should also be taken to ensure that the speed of the driven equipment does not increase after the changeover, as this may lead to increase in the basic power drawn by the driven equipment.

Integrated Systems Approach

There is always a tendency among industrial users and consultants to start with replacement of standard motors with high efficiency motors, as an initial consideration in energy conservation programs. This approach needs a critical review, as it is the end uses which consume lot of energy and it is very important to understand and analyze the system which the motor drives; like a compressor, a pump or a fan. This doesn't mean that motors do not deserve attention. But understanding systems and requirements helps to re-size the motor better, if a motor replacement is desired.

A detailed study of end-use i.e. flows, pressures, temperatures etc. and equipment like air compressors, pumps, blowers, refrigeration machines etc. and system components like piping, ducting etc. is required to achieve large savings.

Refrigeration & Air-Conditioning

An integrated systems approach to Refrigeration and Air conditioning emphasizes on the following issues.

Reducing the Need for Refrigeration

- At the present energy prices, the use of chilled water, brine and air-conditioning should be minimized, as these are very expensive utilities.

- For process cooling applications, many foreign machinery suppliers specify chilled water at 10°C to 15°C as these are the normal cooling tower water temperatures in cold countries for most time of the year.
- The possibility of replacing chilled water with cooling water with higher flows can be considered.
- Air-conditioning should be restricted to small spaces, as guided by process requirements. Comfort air-conditioning should be provided only if necessary in small areas.

<u>Increase Temperature Settings</u>

- Operation at 1ºC higher temperature can save about 3% energy. Hence the opportunity to operate at higher chilled water/brine temperatures should not be missed, after careful trials to assess its impact on process productivity and quality.
- For comfort air-conditioning, operation at 26º or 27ºC air temperature, instead of 24ºC, is possible, provided better air movement is provided with fans.

<u>Reduce Heat Ingress</u>

- Vessels, pipelines and pipe fittings (like valves, flanges, bends etc.) handling refrigerant, chilled water or brine should be well insulated.
- For air-conditioned spaces and cold stores, appropriate methods like double doors, fast closing doors, air curtains and low emissivity films (sun control) for glass windows should be incorporated.

<u>Better Heat Exchanger Design and Maintenance</u>

- Use of larger and better heat exchangers (evaporators & condensers) can help in increasing the refrigerant temperature in the evaporator and decreasing the temperature in the condenser for the same end use temperatures and cooling loads. The potential for savings can be 10% to 30%. This can be ideally addressed at the time of purchase of new equipment.
- The quality of circulating chilled and cooling water should be maintained within tolerable limits to prevent scaling and ensure efficient heat transfer. Proper water treatment is necessary for maintaining the efficiency of a refrigeration plant.

<u>Better Monitoring & Control Techniques</u>

- Good control of the compressor based on accurate sensing of end use temperatures can result in significant savings in systems prone to super-cooling.
- In addition, for air-conditioning systems, use of occupancy sensors can save significant amount of energy.

New Developments for Relative Humidity Control

- Use of special air-to-air heat exchangers can eliminate the need for duct heaters and desiccant dehumidifiers for relative humidity control. By use of these new technologies, some plants have achieved 30 to 50% energy savings.
- Energy Storage
- Some electricity boards have adopted Time of Use energy pricing, which implies higher energy prices during certain hours. By operation of compressors in off-peak hours (when energy price is low), Cooling Effect can be stored in ice banks, some special salts etc.
- In addition to the advantage of lower energy cost, this method can also help reduce the peak kW and kVA demand of the plant, resulting in lower Maximum Demand charges.

Inter-fuel Substitution: Use of Absorption Chillers

- Vapor Absorption System, which uses a heat source to achieve cooling, can reduce the electricity requirement by 80 to 90%. The economics depends on the cost of heat energy. This technology has found good acceptance in locations having waste heat or access to cheaper alternative fuels.

Drive Transmission

- Directly coupled drives have no transmission losses. However, in the case of belt driven equipment, the possibility of use of more efficient flat belts should be explored.

Electric Motor

- The motor should be selected close the rated power requirement of the end use equipment. For new purchases, high efficiency motors should be may be preferred.

Pumping Systems

Integrated systems approach in a pumping system includes the following:

Optimizing the Use of Water

- Optimal use of water for various applications can significantly reduce the raw water pumping energy consumption.
- Review of water circulation rates to optimize flow rates for process cooling can also have a significant effect on energy consumption

Selection Of Pumps To Match Head / Flow Requirements

- Pumps have a good efficiency in a very narrow flow zone; operation at higher or lower than design flows can lead to drastic drop in efficiency from the design value.
- Mismatch in pump selection is often overcome by throttling of valves, however this leads to large wastage of energy.

Number Of Pumps In A System

For systems with large flow requirements and for critical applications, pumps are generally operated in parallel. The sizing of these pumps also offers the possibility for energy saving for applications where the flow can be varied depending on process conditions or seasons.

Use Of Variable Speed Drives

Use of mechanical, electrical or electronic variable speed drives can help in improving the pumping system efficiency in cases that require variable flow or in cases where the pumps are oversized and the flow is controlled by throttling of valves.

Optimizing Pipeline Sizes

- Pipe friction losses depend on the pipe diameter, material, surface condition and age.
- Use of larger pipes can reduce losses. The pipe pressure drop is proportional to the fifth power of the pipe diameter.

Maintenance

- Wear and tear of pumps and scaling of pipes and heat exchangers can affect the energy consumption.
- Proper maintenance of pumps and proper water treatment is necessary to maintain
- reasonable efficiencies

Monitoring & Control

- Proper instrumentation is necessary to monitor the performance of pumps and associated systems. This can help identify opportunities for optimizing flow, pressure and energy consumption.

Electric Motor

- The motor may be selected close to the rated power requirement of the end use equipment. For new purchases, high efficiency motors may be preferred. Apply high efficiency motor carefully to avoid excess flow due to high full load speed of high efficiency motor.

Compressed Air

Compressed air is an expensive utility. Cost of compressed air is sometimes as high as 10 times energy cost compared to other electro-mechanical alternatives. The useful energy content in compressed air that is available at the end use is only about 10 to 20% even in a well designed system.

The Integrated Systems Approach in Compressed Air System has the following steps.

Reducing Compressed Air Use

- Many uses of compressed air like cleaning, material conveying, scouring, agitation and
- Aeration of liquids etc. is not justified at the present energy prices.
- For applications like cleaning & conveying, blowers can be used. For material conveying, use of efficient alternatives like belts, bucket elevators, screw conveyors etc. can be used. For agitation or aeration of liquids, low-pressure Roots compressors or submersible (pump type) agitators can be used. More efficient, portable electrical tools can replace pneumatic portable tools.
- In many plants, pneumatically operated controls are being replaced by electronic and electrical controls, thus reducing the requirement for instrumentation air. In all these cases, the potential for energy saving is about 80% to 90%.

Pressure Reduction

- A thorough study of the end-use pressure requirements and the compressor discharge pressure should be done. An opportunity to reduce the discharge pressure should not be missed as it can give significant energy savings due reduced compression power as well as reduced air leakage.
- An approximate thumb rule is that 10% reduction in compressor discharge pressure reduces energy consumption by about 5%; the savings due to leakage reduction are additional.
- In cases where higher pressures are set to overcome the problem of pressure fluctuations, increase in receiver capacity and use of newly developed pressure & flow controllers can help reduce pressure settings.

Air Leakage Reduction

- Compressed air leakage can vary from 5% to 70% or higher depending on the house keeping efforts on the compressed air distribution system.
- At the present energy cost, all plants should attempt to operate at leakage levels below 5%. Air leakages generally take place from threaded pipe joints, hose connections, valve stems, buried underground lines etc.

Distribution System

- Decentralized installation of compressors can lead to smaller distribution systems and hence reduced pressure and leakage losses. However, whether a system should be decentralized or centralized depends on the air utilization patterns for various end uses in the plant. If uses are highly variable and the equipments (with significant air consumption) are spread out over a large area, a decentralized system may be preferred, with interconnections with isolation valves for emergencies.
- A decentralized system facilitates switching off compressors when air is not required in a particular area.
- Pipe sizing should be done to minimize pressure drops, say less than 0.3 bars from the receiver at the compressor end.
- Isolation valves should be provided at convenient, accessible locations to shut off air when not required in certain areas for known time periods. Selection of Compressors & Capacity Control
- Compressors should be selected with a good understanding of the air utilization pattern. Reciprocating, Screw or Centrifugal or Roots compressors can be used depending on the pressure, quantum of air required and the air demand variations.
- All compressors have the facility for capacity control; part load efficiencies depend on the type of compressor and the method of capacity control; prolonged operation at part loads results in higher energy consumption.
- Compressors consume 10% to 50% of their rated power (depending on the type of compressor and capacity control method) even at no load. The attempt should be to ensure that the operating compressors run close to their rated load.
- Automatic controls are available to detect and switch off compressors operating in unloaded condition for prolonged period.

<u>Maintenance</u>

- Routine maintenance checks on compressors and the distribution system is necessary to ensure efficient compressed air generation and utilization. The performance of reciprocating compressors can deteriorate significantly due to poor maintenance.

<u>Drive Transmission</u>

- Directly coupled drives have no transmission losses. However, in the case of belt driven equipment, the possibility of use of more efficient, synthetic flat belts should be explored.

Electric Motor

- The motor should be selected close to the rated power requirement of the end-use equipment. For new purchases, high efficiency motors may be preferred.

4. BOILER PLANT

Equipment Scheduling and Operating Practices

Minimize the duration of boiler plant operation.

- For applications with regular schedules, install clock controls to start and stop boilers.
- In applications that require a warm-up period, control boiler operation using
- an optimum-start controller.
- If the boiler plant is used only for comfort heating, limit the operation of the boiler plant based on the outside air temperature.
- In applications where automatic starting and stopping of boilers is not desirable, use automatic controls to signal the starting and shutdown sequence to operators.

Operate boiler auxiliary equipment consistent with boiler operation and load.

- Interlock auxiliary equipment with the boilers it serves.
- Install power switching that prevents unnecessary operation of spare pumps.

Distribute the heating load among boilers in the manner that minimizes total plant operating cost.

- Install an automatic boiler scheduling controller.

In steam systems, keep steam pressure at the minimum that satisfies equipment and distribution requirements.

Boiler Plant Efficiency Measurement

- Test boiler efficiency on a continuing basis.
- Install efficiency instrumentation appropriate for the boiler plant.
- Calibrate boiler plant instruments at appropriate intervals.
- Keep operators proficient in using instrumentation to maximize boiler plant efficiency.

Air-Fuel Ratio

- Optimize the air-fuel ratio.
- Install automatic air-fuel mixture controls.
- Adjust and repair air-fuel ratio controls.

Burner and Fan Systems

- Clean, adjust, and repair burner assemblies at appropriate intervals.
- Eliminate air leaks in air casings, blower housings, and connecting ducts.
- In boilers that are fired at inefficiently high output, reduce the maximum firing rate.

- Install burner systems that provide the best efficiency and other features.
- Replace the motors in burners and fans with models having the highest economical efficiency.
- Replace continuous pilot flames with electrical ignition.
- Install variable-output fan drives on large forced-draft and induced-draft fans.

Draft Control

- Adjust draft for maximum efficiency.
- Correct defects in flue systems and boiler room ventilation that cause draft problems.

<u>Minimize standby losses.</u>

- Control all fans in the combustion air path to stop, and all dampers to close, when the burner is not firing.
- Install an automatic flue damper.
- Install a burner assembly or boiler that minimizes standby losses.
- With cycling burners, adjust the controls to minimize the frequency of firing cycles.

Firesides and Watersides

- Clean firesides at appropriate intervals.
- Install soot blowers in boilers that burn sooting fuels.
- Optimize soot blower operation.
- Clean watersides at appropriate intervals.
- Avoid leaving waterside deposits when deactivating boilers.

Combustion Gas Heat Transfer and Heat Recovery

<u>Install a flue gas heat exchanger to recover additional heat.</u>

- Install a conventional (non-condensing) economizer.
- Install a heat recovery air preheater.
- Install a condensing economizer.
- Install a water spray heat recovery unit.

Condensate, Feedwater, and Water Treatment

<u>Test and treat boiler water on a continuing basis.</u>

- Hire a qualified consultant and contractor to perform water treatment.
- Install automatic water treatment equipment.

<u>Control top and bottom blowdown to maintain required water quality and minimize waste of boiler water.</u>

- Install automatic blowdown control.

Install blowdown heat recovery.

Maximize condensate return.

- Recover the heat from condensate that must be discarded.
- Recover the energy of high-temperature condensate that would be lost by flashing.

Keep vacuum condensate systems operating properly.
Replace pump motors with models having the highest economical efficiency.

Fuel Oil Systems

- Adjust fuel oil temperature to provide the optimum viscosity for burner efficiency.
- Install automatic fuel oil viscosity control equipment.
- Use the most economical heat source for fuel oil heating.
- Use fuel oil additives to improve combustion efficiency and/or improve other fuel oil properties.
- Replace pump motors with models having the highest economical efficiency.

Steam and Water Leakage

- Monitor boiler system water loss.
- Locate and repair steam and water leaks at appropriate intervals.
- Use the most efficient type of steam trap for each application.
- Test and repair steam traps on a continuing basis.
- Install accessory devices to assist in steam trap diagnosis.
- Hire specialists to perform periodic steam trap inspections.
- Recover heat and water from steam vents.

Conduction and Radiation Losses

- Locate and repair defective insulation on all heating plant equipment and piping.
- Minimize cooling or ventilation of pipe tunnels and other unoccupied spaces surrounding hot distribution equipment.
- Route combustion air to the boiler by a path that recovers heat from the boiler room.

System Design for Efficient Low-Load Heating

- In facilities that operate for extended periods with low heating loads, install a small, efficient lead boiler.
- Install localized heating units to allow shutting down the central plant during periods of low load.
- If it is desirable to reduce the boiler operating pressure, eliminate high-pressure steam users or provide separate high- pressure steam boilers.

- If a facility has several boiler plants, provide cross connections that allow shutting down the least efficient boilers.

5. WATER

Water Management

Water management is the efficient and effective use of water. Like energy management, the main goal is to improve profits or reduce costs. Water management is important because water and energy use are strongly related in most facilities. As water consumption goes up, so does energy consumption. A successful water management program depends on a clear and complete understanding of how a facility uses water, and what is the true cost of that water – including water disposal (sewer costs). Basic water management strategies include: 1) reduction of water losses; 2) reduce the amount of water used for desired purposes; and 3) re-use or recycle water when possible.

Water Audits and Water Auditing

Water audits are the first step to take in an effective water management program. Water audits in buildings and industries can save dramatic amounts of money and water through attention to their water-consuming equipment. There are three major types of water users in buildings and industry. They are 1) plumbing fixtures (toilets, sinks, showers, etc); 2) HVAC systems (boilers, cooling towers, etc); 3) landscape irrigation (lawns and grounds); and 4) commercial and industrial process equipment (cooking, cleaning, boilers, steam systems, washing, cooling, etc).

The goals of a water audit for a facility include:

- Identify, quantify, and verify the amount of water used in the facility, and its cost.
- Identify water use reduction measures and water efficiency resource opportunities.
- Determine costs of new equipment and processes, and determine their monetary benefits.
- Perform an economic analysis to determine the measures that are cost effective.

Water auditing information needed includes:

- Facility water and sewer bills for past two years
- Any submeter records of water use in the facility
- Facility floor plans, drawings, and locations of all water and sewer meters
- Facility operating schedules and number of employees and visitors
- Lists of all water using equipment and processes, with number of plumbing fixtures
- Facility maintenance and janitorial schedules
- Facility outdoor water use, applications, quantity, and schedule

Water audit tasks include:

- Walk through facility.
- Record hours of operation for all water using equipment.
- Verify operating schedules and number of facility occupants.
- Determine the amount of water used by each plumbing fixture – List by fixture type.
- Measure or estimate water used by other water consuming equipment – List by system type (HVAC, boiler, cooling tower, etc).
- Analyze data from water meters and water submeters.
- Measure or estimate water use for irrigation (lawn, grounds, etc).
- Estimate water losses in leaks, evaporation, etc.
- Identify specific cost effective projects using SPP or LCC.

Water Use Reduction and Water Efficiency Measures

Some typical water efficiency improvement measures by category are

Toilets, sinks and showers

- Low volume flush. Replace 14 to 28 lpf (liters per flush) toilets, to maximize water savings, with valves and porcelain specifically designed to use 6.4 lpf. Replace urinals with models designed to use 4 lpf or install a waterless (no-flush) urinal.
- Alternative technology. In remote areas, consider replacing water using toilets and urinals with alternative technologies such as composting or incinerator toilets.
- Gray water. Consider non-potable water for toilet and urinal flushing.
- Low-flow showerheads. Install showerheads that are designed to use 10 l/min and aerator or laminar flow devices that use 8.8 l/min.
- Setback valves. Install temporary shut-off valves in faucets. These valves cut off the water flow during intermittent activities like scrubbing or dishwashing. The water can be reactivated at the previous temperature without the need to remix the hot and cold water.
- Motion activation. Install automatic shut-off valves. These can be operated by infrared or ultrasonic sensors, which detect the presence of someone's hands and will shut off water when the hands are removed. However, these devices need to be set properly to operate properly.

Boilers

- Blowdown. Blowdown should be reduced to the minimum possible, which is determined by the feedwater quality and the amount of condensate return. Reducing blowdown also saves large amounts of energy.
- Condensate return. Condensate should be returned to the boiler whenever economically feasible. This saves water by reducing the amount of new makeup water needed and by reducing the amount of blowdown required. Returning the condensate also saves substantial amounts of energy and water treatment costs because condensate is essentially distilled water.

- Fixing steam leaks and bad steam traps. Steam leaks are extremely expensive energy losses, but significant amounts of water are also lost in steam leaks. An estimate of the amount of water lost can be obtained by dividing the annual loss in MJ by the enthalpy of evaporation. Stuck-open steam traps are steam leaks if the condensate is not returned and are still wasteful even if it is returned.

Cooling Towers

- Bleed. Bleed in a cooling tower is almost identical to blowdown in a boiler. The purpose is to prevent impurity buildup. Bleed should be reduced to a minimum and reused if possible. Sometimes bleed can be used to water lawns or as rinse water makeup. However, careful attention must be paid to the chemicals in the water.
- Sewer charge negotiations. Often sewer charges are based on the amount of water consumed. Yet water consumed in a cooling tower does not go into the sewer. Negotiations with municipalities can often reduce the sewer charge substantially if large cooling towers are present. Usually about 1% of the flow rate of water must evaporate for each 6°C drop in water temperature.
- Recycling tower water. Often cooling tower water can be used directly for process cooling instead of using chilled water. When this is possible, large amounts of energy can be saved at the cost of higher water consumption. The trade-off is almost always cost effective.

Commercial and Industrial Processes

It is much more difficult to generalize on ways to save in processes since water can be used in so many different ways in industrial processes. For example, water can be used to cool furnace walls, cool air compressors, wash, rinse, surface-treat, coat, test products, and cool molds and for a wide variety of other uses. Some examples are:

- Recycle rinse water. Often rinse water can be recycled by simple filtering or treatment. In one company, \$30,000 and 120 x 10^6 litres of water were saved annually by simply running rinse water through a sand filter and reusing it.
- Re-use cooling water. Often air compressors, small chillers, and other equipment requiring cooling are cooled with once-through cooling water (i.e., water from the tap is run through the equipment one time and dumped into the sewer). In the same room, tap water may be used as boiler makeup water. Because the cooling water is hot, usually about 35°C, if the cooling water is used as boiler makeup water, significant amounts of water and energy can be saved. One company found it could save about \$1300 and four million litres of water per year for *each air compressor* by re-using the cooling water in other places or by recirculating it through a small cooling tower.
- Reduce flow rates to the minimum necessary. Usually, water flow rates are set too high in washing, coating, or rinsing operations. By setting flow rates at minimum levels, significant water can be saved along with the energy required for pumping.
- Cover open tanks. Often heated tanks are open at the top. Floating balls, cantilevered tops, or flexible slit covers can be used to cover the tanks and

reduce evaporation and heat loss. One plant saved about $12,000 per year in energy and water costs by covering their heated tanks.

Irrigation

- Timer. Install an irrigation timer to appropriately schedule sprinkler use. Verify that emitters are appropriate to the plants being irrigated. Use low flow sprinkler heads instead of turf sprinklers in areas with plants, trees or shrubs.
- Sensing dryness. Use a soil tensiometer or other sensor to determine when the soil is dry and gauge the amount of water needed. If using a variety of automatic controls, make sure they have a manual override feature and that you use it. This way, if it rains, you can cancel your next watering. Rain sensors can also be installed to shut off automated irrigation systems when it is raining.
- Selectivity. Select climate appropriate turf, trees, shrubs and ground cover.
- No strip grass. Eliminate "strip grass" to the greatest extent possible. Small strips of grass, common in parking islands and between sidewalks and the roadway are hard to maintain and difficult to efficiently water, use bushes, mulch, colored tiles, instead.

LIFE CYCLE FEASIBILITY ANALYSIS

Ten Steps To Determining Feasibility Of Energy Efficiency Projects

In ten steps one can apply life cycle cost analysis to determine the economic feasibility of an energy efficiency project. Life cycle cost analysis considers the fact that interest (the cost of capital) diminishes, or “discounts” the value of energy savings more each year. This explains why high interest rates limit the scope of projects.

The 10 steps are

1. Determine old costs (existing baseline conditions).
2. Determine new costs (implementation and beyond).
3. Calculate differences.
4. Choose discount rate.
5. Choose analysis period.
6. Estimate residual value of equipment at end of service life.
7. Calculate present value of annual savings.
8. Calculate present value of investments.
9. Calculate net present value (NPV).
10. Calculate savings-to-investment ratio (SIR) and internal rate of return (IRR).

To illustrate the procedure, the ten steps are applied here to a transformer energy conservation measure (ECM).

1. DETERMINE OLD COSTS (BASELINE CONDITIONS)

a) *Life cycle investments*

Assume old life cycle investments = $0 each year

b) *Annual energy costs*

Old annual energy costs = Old annual energy * cost of energy
= $177,000/yr *(from technical data)*

c) *Annual operations & maintenance (O&M) costs*

O&M = $2500/yr.

- In this case, assume poor maintenance at low cost.
- Examine the situation in each ECM separately for *actual* O&M costs.

Note: It is very important that baseline costs are realistic and taken from actual energy and operating expenses recorded in the most recent years. Hypothetical or calculated baselines are generally not acceptable.

2. DETERMINE NEW COSTS (IMPLEMENTATION AND BEYOND)

a) *Initial investment*

Basic project cost = $78,000 *(from technical data)*

Initial investment = Basic project cost + engineering + profit + contingency + taxes
= Basic project cost * (1 + 0.2 + 0.1 + 0.1 + 0.2)
= $78,000 * 1.6
= $124,800

b) *Life cycle investments*

Assume five year replacement cost = 50% of the initial investment
= 0.5 * $124,800
= $62,400

- The best source of information for future period replacement costs is from manufacturers' recommendations.
- In the absence of manufacturers' recommendations, assume 50% of the initial investment every 5 years.

c) *Annual energy costs*

New annual energy costs = New annual energy * cost of energy
= $132,000 *(from technical data)*

d) *Annual O&M costs* Assume new O&M = $5000/yr

3. CALCULATE DIFFERENCES

a) Life cycle investments

Net life cycle investments = New – old life cycle investments *(see Table 1)*

- Enter projected investments for new and old technology in year 0 in Table 1.
- Enter life cycle investments (future replacement costs not counted in normal O&M) for new technology and old technology in future years in Table 1.
- Assume here replacement costs to be 50% of total project cost in 5 years.
- Subtract old costs from new costs to find net amounts for all years.

Table 1: Life Cycle Investment Schedule

Year	New	Old	Net Amount
0	$124,800	$0	$124,800
1	$0	$0	$0
2	$0	$0	$0
3	$0	$0	$0
4	$0	$0	$0
5	$62,400	$0	$62,400
6	$0	$0	$0
7	$0	$0	$0
8	$0	$0	$0
9	$0	$0	$0

- Investments are considered to be made at the end of each year.
- No investments are considered in year 10 because the analysis period expires at the end of year 10.
- The spreadsheet links the results of Table 1 to Table 4.

b) Annual savings

Annual cost savings = Old energy cost – new energy cost + old O&M – new O&M
= $176,000 - $132,000 + $2500 - $5000
= $41,500

- Enter annual cost savings in Table 2.

4. CHOOSE DISCOUNT RATE

- The discount rate for an investment depends on the type of financing, equity or loan.
- In the case of pure equity financing, the discount rate equals the return on the best possible interest rate on any other project.
- In the case of a loan, the discount rate equals a bank's interest rate.
- If there is a mix of equity and loan, then the project's discount rate is a weighted average of the two separate discount rates.
- Here choose a discount rate r = 12%, (e.g., bank interest rate) and enter in Table 2.

5. CHOOSE ANALYSIS PERIOD

- Because of the high discount rate, the present value of cash flow after 10 years is not substantial, even if equipment's service life is longer.
- Only a short analysis period should be used with a high discount rate, i.e., in a high risk situation.
- Longer analysis periods show greater return with low discount rates.
- If the service life of equipment, such as lamps, is shorter than the analysis period, include period relamping in the investment schedule, Table 1.
- If the service life of equipment, such as boilers, is longer than the analysis period, claim a higher residual value (next step) to reflect the market value before total depreciation.
- Here choose analysis period T = 10 years, and enter in Table 2.

6. ESTIMATE RESIDUAL VALUE OF EQUIPMENT

- As a general rule, residual value at the end of equipment service life can be considered to be 10% of the purchase price of any item that still has market value.
- Equipment that outlives the analysis period may have greater residual value, depending on factors like market demand or the depreciation schedule.
- Boilers and pumps are examples of equipment with residual market value if they have been maintained in good working condition.
- Used light bulbs, insulation and other small items have no market value.
- Here choose residual value = $17,610, and enter in Table 2.

7. CALCULATE PRESENT VALUE OF ANNUAL SAVINGS

Let: PV_{AS} = Total present value of all annual savings
T = Total number of the years in the analysis (here T = 10 years)
AS_t = Annual savings in the year *t*

- Present value of annual savings in a given year is the amount of the savings in that year divided by (1+ discount rate) to the power of the year when the savings occur.
- Total PV of project savings during the analysis period is the sum of all annual PVs.

$$PV_{AS} = \sum_{t=0}^{T} AS_t \frac{1}{(1+r)^t} = AS_1 \frac{1}{(1+r)^1} + AS_2 \frac{1}{(1+r)^2} + \dots + AS_{10} \frac{1}{(1+r)^{10}} \qquad (1)$$

= \$309,982 *(see Table 3)*

- The spreadsheet calculates the value of life cycle project savings in Table 3.

8. CALCULATE PRESENT VALUE OF INVESTMENTS

Let: PV_I = Present value of investments
I_t = Investment in the year *t*

- Present value of an investment in a given year is the amount of the investment in that year divided by (1+ discount rate) to the power of the year when the investment occurs.
- Total investment PV during the analysis period is the sum of all annual PVs.

$$PV_I = \sum_{t=0}^{T} I_t \frac{1}{(1+r)^t} = I_1 \frac{1}{(1+r)^1} + I_2 \frac{1}{(1+r)^2} + \ldots + I_{10} \frac{1}{(1+r)^{10}} \qquad (2)$$

= \$189,873 *(see Table 4)*

- The spreadsheet calculates life cycle project investments in Table 4.

9. CALCULATE NET PRESENT VALUE (NPV)

- The net present value (NPV) of a project is its life cycle net savings.

$$\begin{aligned} NPV &= \text{Present value of savings - Present value of investments} && (3) \\ &= PV_{AS} - PV_{I} \\ &= \$309{,}982 - \$189{,}873 \\ &= \$120{,}109 \end{aligned}$$

- NPV shows the total potential earnings of a project.
- NPV considers the effect of interest on future net savings.
- If NPV > 0, a project is profitable (economically feasible).
- NPV is a major decision making tool for owners of energy projects.

10. CALCULATE SAVINGS-TO-INVESTMENT RATIO (SIR) AND INTERNAL RATE OF RETURN (IRR)

- The savings-to-investment ratio (SIR) and internal rate of return (IRR) are also life cycle feasibility indicators that consider the PV of savings and investments.

a) Savings-to-investment ratio (SIR)

SIR = Present value of savings / Present value of investments (4)

$= PV_{AS} / PV_{I}$

= \$309,982 / \$189,873

= 1.6

- If SIR >1.0, a project is profitable (economically feasible).
- SIR may also be a major decision making tool for owners of energy projects.

b) Internal Rate of Return (IRR)

- IRR is the hypothetical discount rate that causes SIR = 1.0.
- IRR requires a repetitive calculation, best done by a computer.
- If the IRR is at least as high as the discount rate used in the analysis, the investment is worthwhile (economically feasible).
- A high IRR earns more profit per investment dollar, but restricts a project's scope.
- IRR is a major decision making tool for lenders, usually the first question they ask.

Life Cycle Cost Analysis Spreadsheet, Transformer ECM

Table 2: Data Entry

Annual savings	$3,907
Net initial investment	$12,606
Discount rate	20%
Analysis period (years)	10
Residual value	$0

Table 3: Savings Calculations

Formula: PV annual savings = Annual savings / (1 + discount rate)^{year}

Year	0	1	2	3	4	5	6	7	8	9	10
Annual savings	$0	$3,907	$3,907	$3,907	$3,907	$3,907	$3,907	$3,907	$3,907	$3,907	$3,907
PV annual savings	$0	$3,256	$2,713	$2,261	$1,884	$1,570	$1,308	$1,090	$909	$757	$631
Σ PV annual savings	$16,380										

Table 4: Investment Calculations

Formula: PV life cycle investment = Life cycle investment / (1 + discount rate)^{year}

Year	0	1	2	3	4	5	6	7	8	9	Residual Value (negative)
Net life cycle investment	$12,606	$0	$0	$0	$0	$6,303	$0	$0	$0	$0	($0)
PV life cycle investment	$12,606	$0	$0	$0	$0	$2,533	$0	$0	$0	$0	($0)
Σ PV life cycle investment	$15,139										

Table 5: Results

Simple payback (years)	3.2
Net present value (NPV)	$1,241
Savings-to-investment ratio (SIR)	1.08
Internal rate of return (IRR)	23%

Formulas:

Simple payback	=	Initial investment / annual savings
Net present value	=	Σ PV annual savings - Σ PV life cycle investm
Savings-to-investment ratio	=	Σ PV annual savings / Σ PV life cycle investm
Internal rate of return	=	Discount rate, where SIR = 1.0, or NPV = 0

Note: Simple payback (SPB) is not considered a good feasibility indicator. It only indicates how long the initial investment will be "at risk."

- SPB does not account for the cost of capital (discount rate and PV).
- SPB does not account for lifetime investments (irregular expenses, periodic replacement costs, avoided replacement costs).
- SPB does not show how much investment is too much.

ENERGY AUDIT REPORT

The energy audit report to the client should be written according to the following format, then discussed with the client upon delivery.

Executive Summary

- Simple, straightforward, to the point:

  "What do you want me to do?"

  1. Introduction to project
  2. Summary table
  3. Performance of measures
  4. Discussion of benefits and issues important to client

Building Information

- General Background of the Facility, Mechanical Systems, and Operation

  1. Envelope description
  2. Floor plans
  3. Operating schedule
  4. Occupancy patterns
  5. Energy use in the plant
  6. Mechanical systems
  7. Operation and maintenance practices

Utility Summary

- Energy Accounting Data and Graphics for the Last Two Years

  1. Energy use index (EUI)
  2. Monthly consumption profiles
  3. Demand profile
  4. Energy use history
  5. Rate schedules/rate alternatives

Energy Conservation Measures (ECMs)

- Energy Conservation Recommendations and Support Calculations

  1. List of ECMs that meet financial criteria
  2. Descriptions
  3. Energy calculations
  4. NPV, SIR, IRR
  5. Emissions reductions
  6. ECMs considered but not recommended

Operation and Maintenance Measures (O&Ms)

- Descriptions of Low-Cost Improvements

  1. Potential operational changes
  2. Maintenance issues affecting energy use
  3. Energy and equipment savings estimates
  4. Costs to implement measures

Appendices

- Support Material and Technical Information

  1. Floor plans, site notes, photos
  2. Audit data forms
  3. Computer simulation runs
  4. Motor and lighting inventory
  5. Energy program information and applications

APPENDIX: Checklist and tips for energy efficiency

The following pages provide the checklist and tips for energy efficiency, which can be readily used to look at the possibilities of energy saving and the items to be tackled during the energy audit for analysis.

Electricity

- Optimize the tariff structure with utility supplier
- Schedule your operations to maintain a high load factor
- Shift loads to off-peak times if possible
- Minimize maximum demand by tripping loads through a demand controller
- Stagger start-up times for equipment with large starting currents to minimize load peaking
- Use standby electric generation equipment for on-peak high load periods
- Correct power factor to at least 0.90 under rated load conditions
- Relocate transformers close to main loads
- Set transformer taps to optimum settings
- Disconnect primary power to transformers that do not serve any active loads
- Consider on-site electric generation or cogeneration
- Check utility electric meter with your own meter.
- Shut off unnecessary computers, printers, and copiers at night

Motors

- Properly size to the load for optimum efficiency (High efficiency motors offer of 4 – 5% higher efficiency than standard motors)
- Use energy-efficient motors where economical
- Use synchronous motors to improve power factor
- Check alignment
- Provide proper ventilation (For every 10 ^{0}C increase in motor operating temperature over recommended peak, the motor life is estimated to be halved)
- Check for under-voltage and over-voltage conditions
- Balance the three-phase power supply (An imbalanced voltage can reduce 3 – 5% in motor input power)
- Demand efficiency restoration after motor rewinding (If rewinding is not done properly, the efficiency can be reduced by 5 – 8%)

Drives

- Use variable-speed drives for large variable loads
- Use high-efficiency gear sets
- Use precision alignment

- Check belt tension regularly
- Eliminate variable-pitch pulleys
- Use flat belts as alternatives to v-belts
- Use synthetic lubricants for large gearboxes
- Eliminate eddy current couplings
- Shut them off when not needed

Fans

- Use smooth, well-rounded air inlet cones for fan air intakes
- Avoid poor flow distribution at the fan inlet
- Minimize fan inlet and outlet obstructions
- Clean screens, filters, and fan blades regularly
- Use aerofoil-shaped fan blades
- Minimize fan speed
- Use low-slip or flat belts
- Check belt tension regularly
- Eliminate variable pitch pulleys
- Use variable speed drives for large variable fan loads
- Use energy-efficient motors for continuous or near-continuous operation
- Eliminate leaks in ductwork
- Minimize bends in ductwork
- Turn fans off when not needed

Blowers

- Use smooth, well-rounded air inlet ducts or cones for air intakes
- Minimize blower inlet and outlet obstructions
- Clean screens and filters regularly
- Minimize blower speed
- Use low-slop or no-slip belts
- Check belt tension regularly
- Eliminate variable pitch pulleys
- Use variable speed drives for large variable blower loads
- Use energy-efficient motors for continuous or near-continuous operation
- Eliminate ductwork leaks
- Turn blowers off when they are not needed

Pumps

- Operate pumping near best efficiency point
- Modify pumping to minimize throttling
- Adapt to wide load variation with variable speed drives or sequenced control of smaller units

- Stop running both pumps-and an auto-start for an on-line spare or add a booster pump in the problem area
- Use booster pumps for small loads requiring higher pressures
- Increase fluid temperature differentials to reduce pumping rates
- Repair seals and packing to minimize water waste
- Balance the system to minimize flows and reduce pump water requirements
- Use siphon effect to advantage; don't waster pumping head with a free-fall (gravity) return

Compressors

- Consider variable speed drive for variable load on positive displacement compressors
- Use a synthetic lubricant if the compressor manufacturer permits it
- Be sure lubricating oil temperature is not too high (oil degradation and lowered viscosity) and not too low (condensation contamination)
- Change the oil filter regularly
- Periodically inspect compressor intercoolers for proper functioning
- Use waste heat from a very large compressor to power an absorption chiller or preheat process or utility feeds
- Establish a compressor efficiency-maintenance program. Start with an energy audit and follow-up, then make a compressor efficiency-maintenance program a part of your continuous energy management program

Compressed air

- Install a control system to coordinate multiple air compressors
- Study part-load characteristics and cycling costs to determine the most-efficient mode for operating multiple air compressors
- Avoid over sizing-match the connected load
- Load up modulation-controlled air compressors. (They use almost as much power at partial load as at full load)
- Turn off the back-up air compressor until it is needed
- Reduce air compressor discharge pressure to the lowest acceptable setting (Reduction of 1 kg/cm2 air pressure (8 kg/cm2 to 7 kg/cm2) would result in 9% input power savings. This will also reduce compressed air leakage rates by 10%)
- Use the highest reasonable dryer dew point settings.
- Turn off refrigerated and heated air dryers when the air compressors are off
- Use a control system to minimize heatless desiccant dryer purging
- Minimize purges, leaks, excessive pressure drops, and condensation accumulation (Compressed air leak from 1 mm hole size at 7kg/cm2 pressure would mean power loss equivalent to 0.5 kW)
- Use drain controls instead of continuous air bleeds though the drains
- Consider engine-driven or steam-driven air compression to reduce electrical demand charges

- Replace standard v-belts with high-efficiency flat belts as the old v-belts wear out
- Use a small air compressor when major production load is off
- Take air compressor intake air from the coolest (but not air conditioned) location (Every 5o C reduction in intake air temperature would result in 1% reduction in compressor power consumption)
- Use an air-cooled aftercooler to heat building makeup air in winter
- Be sure that heat exchangers are not fouled (e.g. with oil)
- Be sure that air/oil separators are not fouled
- Monitor pressure drops across suction and discharge filters and clean or replace filters promptly upon alarm
- Use a properly sized compressed air storage receiver
- Minimize disposal costs by using lubricant that is fully demulsible and an effective oil-water separator
- Consider alternatives to compressed air such ass blowers for cooling, hydraulic rather than air cylinder, electric rather than air actuators, and electronic rather than pneumatic controls
- Use nozzles or venturi-type devices rather than blowing with open compressed air lines
- Check for leaking drain valves on compressed air filter/regulator sets. Certain rubber-type valves may leak continuously after they age and crack
- Industry environments, control packaging lines with high-intensity photocell units instead of standard units with continuous air purging of lenses and reflectors
- Establish a compressed air efficiency-maintenance program. Start with an energy audit and follow-up, then make a compressed air efficiency-maintenance program a part of your continuous energy management program

Chillers

- Increase the chilled water temperature set point if possible
- Use the lowest temperature condenser water available that the chiller can handle (Reducing condensing temperature by 5.5oC, results in a 20 – 25% decrease in compressor power consumption)
- Increase the evaporator temperature (5.5oC increase in evaporator temperature reduces compressor power consumption by 20 – 25%)
- Clean heat exchangers when fouled (1 mm scale build-up on condenser tubes can increase energy consumption by 40%)
- Optimize condenser water flow rate and refrigerated water flow rate
- Replace old chillers or compressors with new higher-efficiency models
- Use water-cooled rather than air-cooled chiller condensers
- Use energy-efficient motors for continuous or near-continuous operation
- Specify appropriate fouling factors for condensers
- Do not overcharge oil
- Install a control system to coordinate multiple chillers
- Study part-load characteristics and cycling costs to determine the most-efficient mode for operating multiple chillers

- Run the chillers with the lowest operating costs to serve base load
- Avoid oversizing match the connected load
- Isolate off-line chillers and cooling towers
- Establish a chiller efficiency-maintenance program. Start with an energy audit and follow-up, then make a chiller efficiency-maintenance program a part of your continuous energy management program

HVAC (Heating / Ventilation / Air Conditioning)

- Tune up the HVAC control system
- Consider installing a building automation system (BAS) or energy management system (EMS) or restoring an out-of-service one.
- Balance the system to minimize flows and reduce blower/fan/pump power requirements
- Eliminate or reduce reheat whenever possible
- Use appropriate HVAC thermostat setback
- Use morning pre-cooling in summer and pre-heating in winter (i.e. before electrical peak hours)
- Use building thermal lag to minimize HVAC equipment operating time
- In winter during unoccupied periods, allow temperatures to fall as low as possible without freezing water lines or damaging stored materials
- In summer during unoccupied periods, allow temperatures to rise as high as possible without damaging stored materials
- Improve control and utilization of outside air
- Use air-to-air heat exchangers to reduce energy requirements for heating and cooling of outside air
- Reduce HVAC system operating hours (e.g. computer rooms)
- Provide dedicated outside air supply to kitchens, cleaning rooms, combustion equipment, etc to avoid excessive exhausting of conditioned air
- Use evaporative cooling in dry climates
- Reduce humidification or dehumidification where possible
- Use atomization rather than steam for humidification where possible
- Clean HVAC unit coils periodically and comb mashed fins
- Upgrade filter banks to reduce pressure drop and thus lower fan power requirements
- Check HVAC filters on a schedule (at least monthly) and clean/change if appropriate
- Check pneumatic controls air compressors for proper operation, cycling, and maintenance
- Isolate air conditioned loading dock areas and cool storage areas using high-speed doors or clear PVC strip curtains
- Install ceiling fans to minimize thermal stratification in high-bay areas
- Relocate air diffusers to optimum heights in areas with high ceilings
- Consider reducing ceiling heights
- Eliminate obstructions in front of radiators, baseboard heaters, etc.

- Check reflectors on infrared heaters for cleanliness and proper beam direction
- Use professionally-designed industrial ventilation hoods for dust and vapor control
- Use local infrared heat for personnel rather than heating the entire area
- Use spot cooling and heating (e.g. use ceiling fans for personnel rather than cooling the entire area)
- Purchase only high-efficiency models for HVAC window units
- Put HVAC window units on timer control
- Don't oversize cooling units, (Oversized units will "short cycle" which results in poor humidity control)
- Install multi-fueling capability and run with the cheapest fuel available at the time
- Consider dedicated make-up air fir exhaust hoods. (Why exhaust the air conditioning or heat if you don't need to?)
- Minimize HVAC fan speeds
- Consider desiccant drying of outside air to reduce cooling requirements in humid climates
- Consider ground source heat pumps
- Seal leaky HVAC ductwork
- Seal all leaks around coils
- Repair loose or damaged flexible connections (including those under air handling units)
- Eliminate simultaneous heating and cooling during seasonal transition periods
- Zone HVAC air and water systems to minimize energy use
- Inspect, clean, lubricate, and adjust damper blades and linkages
- Establish an HVAC efficiency-maintenance program. Start with an energy audit and follow-up, then make an HVAC efficiency-maintenance program a part of your continuous energy management program

Refrigeration

- Use water-cooled condensers rather than air-cooled condensers
- Challenge the need for refrigeration, particularly for old batch processes
- Avoid oversizing match the connected load
- Consider gas-powered refrigeration equipment to minimize electrical demand charges
- Use "free cooling" to allow chiller shutdown in cold weather
- Use refrigerated water loads in series if possible
- Convert firewater or other tanks to thermal storage
- Don't assume that the old way is still the best- particularly for energy intensive low temperature systems
- Correct inappropriate brine or glycol concentration that adversely affects heat transfer and/or pumping energy. **If it sweats, insulate it, but if it is corroding, replace it first.**
- Make adjustments to minimize hot gas bypass operation
- Inspect moisture/liquid indicators

- Consider change of refrigerant type if it will improve efficiency
- Check for correct refrigerant charge level
- Inspect the purge for air and water leaks
- Establish a refrigeration efficiency-maintenance program. Start with an energy audit and follow-up, then make a refrigeration efficiency-maintenance program a part of your continuous energy management program

Cooling towers

- Control cooling tower fans based on leaving water temperatures
- Control to the optimum water temperature as determined from cooling tower and chiller performance data
- Use two-speed or variable-speed drives for cooling tower fan control if the fans are few. Stage the cooling tower fans with on-off control if there are many
- Turn off unnecessary cooling tower fans when loads are reduced
- Cover hot water basins (to minimize algae growth that contributes to fouling)
- Balance flow to cooling tower hot water basins
- Periodically clean plugged cooling tower water distribution nozzles
- Install new nozzles to obtain a more-uniform water pattern
- Replace splash bars with self-extinguishing PVC cellular-film fill
- On old counterflow cooling towers, replace old spray-type nozzles with new square-spray ABS practically-non-clogging nozzles
- Replace slat-type drift eliminators with high efficiency, low pressure-drop, self-extinguishing, PVC cellular units
- If possible, follow manufacturer's recommended clearances around cooling towers and relocate or modify structures, signs, fences, dumpsters, etc. that interfere with air intake or exhaust
- Optimize cooling tower fan blade angle on a seasonal and/or load basis
- Correct excessive and/or uneven fan blade tip clearance and poor fan balance
- Use a velocity pressure recovery fan ring
- Divert clean air-conditioned building exhaust to the cooling tower during hot weather
- Re-line leaking cooling tower cold water basins
- Check water overflow pipes for proper operating level
- Optimize chemical use
- Consider side stream water treatment
- Restrict flow through large loads to design values
- Shut off loads that are not in service
- Take blowdown water from the return water header
- Optimize blowdown flow rate
- Automate blowdown to minimize it
- Send blowdown to other uses (Remember, the blowdown does not have to be removed at the cooling tower. It can be removed anywhere in the piping system
- Implement a cooling tower winterization plant to minimize ice build-up

- Install interlocks to prevent fan operation when there is no water flow
- Establish a cooling tower efficiency-maintenance program. Start with an energy audit and follow-up, then make a cooling tower efficiency-maintenance program a part of your continuous energy management program

Lighting

- Reduce excessive illumination levels to standard levels using switching, delamping, etc (Know the electrical effects before doing delamping.)
- Aggressively control lighting with clock timers, delay timers, photocells, and/or occupancy sensors
- Install efficient alternatives to incandescent lighting, mercury vapor lighting, etc. Efficiency (lumens/watt) of various technologies range from best to worst approximately as follows: low pressure sodium, high pressure sodium, metal halide, fluorescent, mercury vapor, incandescent
- Select ballasts and lamps carefully with high power factor and long-term efficiency in mind
- Upgrade obsolete fluorescent systems to compact fluorescents and electronic ballasts
- Consider lowering the fixtures to enable using less of them
- Consider daylighting, skylights, etc.
- Consider painting the walls a lighter color and using less lighting fixtures or lower wattages
- Use task lighting and reduce background illumination
- Re-evaluate exterior lighting strategy, type and control. Control it aggressively
- Change exit signs from incandescent to LED

DG sets

- Optimize loading
- Use waste heat to generate steam/hot water/ power an absorption chiller or preheat process or utility feeds
- Use jacket and heat cooling water for process needs
- Clean air filters regularly
- Insulate exhaust pipes to reduce DG set room temperatures
- Use cheaper heavy fuel oil for capacities more than 1 MW

Buildings

- Seal exterior cracks/openings/gaps with caulk, gasketing, weatherstripping, etc.
- Consider new thermal doors, thermal windows, roofing insulation, etc.
- Install windbreaks near exterior doors
- Replace single-pane glass with insulating glass
- Consider covering some window and skylight areas with insulated wall panels inside the building

- If visibility is not required but light is required, consider replacing exterior windows with insulated glass block
- Consider tinted glass, reflective glass, coatings, awnings, overhangs, draperies, blinds, and shades for sunlit exterior windows
- Use landscaping to advantage
- Add vestibules or revolving doors to primary exterior personnel doors
- Consider automatic doors, air curtains, strip doors, etc. at high-traffic passages between conditioned and non-conditioned spaces. Use self-closing doors if possible
- Use intermediate doors in stairways and vertical passages to minimize building stack effect
- Use dock seals at shipping and receiving doors
- Bring Cleaning personnel in during the working day or as soon after as possible to minimize lighting and HVAC costs

Steam Generation and distribution

- Check if a flow diagram is available in the boiler room and try to obtain a copy
- If not available draft a simple one
- Look if a logbook is maintained and obtain copies for a typical week
- Note the technical specifications of the boilers and burners from their labels
- Note the operating pressure and temperature
- Check if metering and control instruments are installed and their working condition
- Check if there is a hole in the exhaust gas track for the combustion analyzer. If not ask operators to drill one.
- Check for water and steam leaks
- Check if boiler, pipe work and condensate tank are adequately insulated
- Check if oil tanks (HFO) and oil pipelines heated by steam or electricity are insulated
- Check if housekeeping is adequately done
- Identify how much condensate is returned and if it is metered. If not try to estimate by other means.
- Check if blow down practice is adequate and blow down valve is not leaking
- Check if flue gas dampers are installed in stand by boilers to avoid heat losses
- Check the possibility to retrofit boilers with economizer if not equipped already.
- Check steam distribution system for proper insulation of pipelines, valves and fittings
- Conduct leakage test for steam traps, valves and fittings
- Develop Mass And Energy Balance of Boilers in factory

Water & Wastewater

- Recycle water, particularly for uses with less-critical quality requirements
- Recycle water, especially if sewer costs are based on water consumption

- Balance closed systems to minimize flows and reduce pump power requirements
- Eliminate once-through cooling with water
- Use the least expensive type of water that will satisfy the requirement
- Fix water leaks
- Test for underground water leaks. (it’s easy to do over a holiday shutdown)
- Check water overflow pipes for proper operating level
- Automate blowdown to minimize it
- Provide proper tools for wash down – especially self-closing nozzles
- Install efficient irrigation
- Reduce flows at water sampling stations
- Eliminate continuous overflow at water tanks
- Promptly repair leaking toilets and faucets
- Use water restrictors on faucets, showers, etc
- Use self-closing type faucets in restrooms
- Use the lowest possible hot water temperature
- Do not use a heating system hot water boiler to provide service hot water during the cooling season install a smaller, more-efficient system for the cooling season service hot water
- If water must be heated electrically, consider accumulation in a large insulated storage tank to minimize heating at on-peak electric rates
- Use multiple, distributed, small water heaters to minimize thermal losses in large piping systems
- Use freeze protection valves rather than manual bleeding of lines
- Consider leased and mobile water treatment systems, especially for deionized water
- Seal sumps to prevent seepage inward from necessitating extra sump pump operation
- Install pretreatment to reduce TOC and BOD surcharges
- Verify the water meter readings. (You’d be amazed how long a meter reading can be estimated after the meter breaks or the meter pit fills with water!)
- Verify the sewer flows if the sewer bills are based on them

Miscellaneous

- Meter any unmetered utilities. Know what is normal efficient use. Track down causes of deviations
- Shut down spare, idling, or unneeded equipment
- Make sure that all of the utilities to redundant areas are turned off-including utilities like compressed air and cooling water
- Install automatic control to efficiently coordinate multiple air compressors, chillers, cooling tower cells, boilers, etc
- Renegotiate utilities contracts to reflect current loads and variations
- Consider buying utilities from neighbors, particularly to handle peaks
- Leased space often has low-bid inefficient equipment. Consider upgrades if your lease will continue for several more years

- Adjust fluid temperatures within acceptable limits to minimize undesirable heat transfer in long pipelines
- Minimize use of flow bypasses and minimize bypass flow rates
- Provide restriction orifices in purges (nitrogen, steam, etc.)
- Eliminate unnecessary flow measurement orifices
- Consider alternatives to high pressure drops across valves
- Turn off winter heat tracing that is on in summer